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16. ABSTRACT

This report documents bench scale and pilot plant studies conducted to develop and improve a treatment system for combined sewer overflows. The majority of pollutants were of a particulate nature, which indicated solids/liquid separation processes could provide effective treatment.

Screening/flotation and sequential screening treatment processes were investigated on a 5 mgd demonstration basis. It was concluded that screening/flotation is an effective method of reducing pollution caused by combined sewer overflows, and the overall pollutant removals ranged between 60% - 75%. On the other hand, sequential screening was not as effective a treatment method as indicated by overall pollutant removals of about 30%. Moreover, it was concluded that the use of three screens in series did not show any advantage over a single screen.

Effluent flow pressurization mode of operation and powdered activated carbon were investigated for improving the performance of screening/flotation treatment, and the results obtained showed no apparent improvement. Also, investigation of microscreening (22 micron) for polishing flotation effluent indicated that overall particulate removal efficiency of an additional 5% to 10% could be achieved.

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SCREENING/FLOTATION TREATMENT OF COMBINED SEWER OVERFLOWS

Volume I - Bench Scale and Pilot Plant Investigations

by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problems, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The study contained herein documents bench scale and pilot plant investigations conducted to develop and improve a treatment system (screening/flotation) for handling combined sewer overflows. It was found that a screening/flotation treatment system is an effective method of reducing the pollution caused by combined sewer overflows.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

This report documents bench scale and pilot plant studies conducted to develop and improve a treatment system for combined sewer overflows. The processes of chemical oxidation, screening, dissolved-air flotation and disinfection were evaluated in the laboratory. It was determined that chemical oxidation was not feasible. The majority of the pollutants were of a particulate nature, which indicated solids/liquid separation processes could provide effective treatment. Screening/flotation and sequential screening were the solids/liquid separation processes investigated on a demonstration basis.

A 5 mgd screening (one drum screen) and dissolved-air flotation demonstration test facility was designed and installed at the Hawley Road CSO outfall in Milwaukee, Wisconsin. The treatment system was operated successfully on 55 combined sewer overflows during 1969 and 1970 and on 8 overflow events during the 1971-1972 season. It was concluded that screening/flotation is an effective method of reducing pollution caused by combined sewer overflows. The overall pollutant removals measured in terms of suspended solids, volatile suspended solids, BOD and COD ranged between 60-75%

A 5 mgd sequential screening (three drum screens in series) demonstration test facility was also designed and installed at the Hawley Road CSO outfall in Milwaukee. The screening system was operated during 1971 on 21 combined sewer overflows. The overall pollutant removals measured in terms of suspended solids, volatile suspended solids, BOD, COD and TOC were about 30%. Addition of chemical flocculants or variation in hydraulic and solids loadings did not effect significant improvement in the removal efficiencies. It was concluded that the use of three screens in series did not show any advantage over a single screen.

Subsequent field work, based upon bench scale testing, was concentrated on improving or upgrading the performance of the screening/flotation demonstration system. Effluent flow pressurization mode of operation and powdered activated carbon were investigated for improving performance, and the results obtained showed no apparent improvement.

Investigation of microscreening (22 micron) for polishing flotation effluent indicated that overall particulate removal efficiency of an additional 5 to 10% could be achieved.

This report was submitted as partial fulfillment of contract number 14-12-40 under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from October 1967 to March 1975.

TABLE OF CONTENTS

	PAGE
ABSTRACT	iv
LIST OF TABLES	ix
LIST OF FIGURES	xiii
ACKNOWLEDGEMENTS	xiv
SECTION I - CONCLUSIONS	1
SECTION II - RECOMMENDATIONS	4
SECTION III - INTRODUCTION	5
SECTION IV - LITERATURE SEARCH	7
Characteristics of Combined Sewer Overflows	7
Removal of Solids by Screening	11
Dissolved-Air Flotation	13
Disinfection of Combined Sewer Overflows	15
Ultraviolet Light Disinfection	15
Disinfection by Chemicals	16
Summary Remarks	17
SECTION V - SITE SELECTION AND PRELIMINARY INVESTIGATIONS	19
Site Selection	19
Preliminary Investigations	23
Conclusions - Preliminary Investigations	33
SECTION VI - DESIGN AND CONSTRUCTION OF THE 5 MGD SCREENING/ FLOTATION DEMONSTRATION FACILITY	34
Design of Screen	34
Floatation System Design	39
Design of Supporting System	40
Operation Methods and Test Plan	43
Methods and Operational Procedures	43
Sampling Procedures	43
Test Plan	46

TABLE OF CONTENTS (CONTINUED)

PAGE

SECTION VII - SCREENING/FLOTATION OPERATING RESULTS (1969-1970) AND DISCUSSION 48

Characterization of Raw Waste 48
Results of the Screening Operation 54
Operation of the Flotation System 56
Operational Difficulties 66
Disinfection of Combined Overflows 67
Conceptual Design 67
  Pumping System 69
  Screening System 70
  Flotation System 72
Economic Considerations 77

SECTION VIII - DESIGN AND CONSTRUCTION OF THE 5 MGD SEQUENTIAL SCREENING DEMONSTRATION FACILITY 81

Location of Site 81
Treatment System Components 81
Design of the Screening System 84
Design of Supporting Systems 87

SECTION IX - SEQUENTIAL SCREENING OPERATING RESULTS (1971) AND DISCUSSION 91

Operational Methods and Procedures 91
Sampling Procedures 91
Test Plan 92
Raw Wastewater Quality 93
Operation of the Sequential Screening System 96
Bench Scale Screening Tests 103
Operation of the Backwash System 108
Disinfection of Combined Sewer Overflows 108

SECTION X - INVESTIGATIONS CONDUCTED FOR UPGRADING SCREENING/FLOTATION PERFORMANCE 110

Screening/Flotation Using Effluent Pressurization and Microscreening of Flotation Effluent 111
Test Plan 118
Coarse Screening 119
Dissolved-Air Flotation Operation 121
Flotation Effluent Screening 125
Microscreening of Raw CSO 125
Powdered Activated Carbon Addition 130

TABLE OF CONTENTS (CONTINUED)

PAGE

SECTION XI - REFERENCES 142

SECTION XII - APPENDICES 146

APPENDIX A - CHEMICAL OXIDATION STUDIES 146

LITERATURE SEARCH 146
- Hydrogen Peroxide 147
- Ozone 149
- Oxidation by Chlorine 152
- Oxidation by Oxy-Acids and their Salts 154
- Electro-Chemical Oxidation 155
- Combination of Oxidants 155

LABORATORY INVESTIGATIONS 156
- General Test Procedures 156
- Special Test Procedures with Various Chemical Oxidants 156
- Ozone Oxidation System 159

RESULTS AND DISCUSSION 161
- Oxidation with Hydrogen Peroxide 161
- Oxidation with Chlorine 164
- Oxidation with Combined System of Hydrogen Peroxide and Chlorine 167
- Oxidation with Ozone 167
- Oxidation with Gamma Radiation 173

SUMMARY AND CONCLUSIONS 173

REFERENCES - APPENDIX A 175

APPENDIX B - BENCH SCALE STUDIES FOR UPGRADING FLOTATION TREATED COMBINED SEWER OVERFLOWS 178

INTRODUCTION 178
- Scope of Work 178
- Test Procedures 179

RESULTS AND EVALUATIONS 184
- Operation of the Field Treatment System During 1972 184
- Evaluation of Various Processes for Upgrading Flotation Effluents 184
- High Rate Filtration 187
- Microscreening 187
- Carbon-Flotation Tests 187

TABLE OF CONTENTS - APPENDIX B (CONTINUED)

PAGE

Ozone Oxidation 196
Removal of Total Phosphates 196

DISCUSSION 199

SUMMARY AND CONCLUSIONS 201

REFERENCES - APPENDIX B 203

APPENDIX C - ANALYTICAL PROCEDURES 204

Analytical Instruments and Apparatus 204
Analytical Procedures and Analyses 204

APPENDIX D - BNECH SCALE TEST PROCEDURES 207

Dissolved-Air Flotation Test Procedure 207
Microscreening Test Procedure 209

APPENDIX E - DEMONSTRATION SYSTEM, OPERATING DATA AND STATISTICAL PROCEDURES 212

OPERATING DATA 212
Screening/Flotation System 212
1969-1970 Data 212
1971-1972 Data 238
1973 Data 246
1974 Data 254

Sequential Screening System 264
1971 Data

Microscreening System 272
Flotation Effluent Treatment (1973) 273
Raw CSO Treatment (1973) 275

STATISTICAL PROCEDURES 277

APPENDIX F - ENGLISH UNITS AND CONVERSION TO METRIC UNITS 280

LIST OF TABLES

Table Page

1 Quality of Combined Sewer Overflows 10
2 Characteristics of Combined Overflow - Hawley Road Site 26
3 Summary of Preliminary Screening Data 27
4 Summary of Preliminary Flotation Data 30
5 Preliminary Screening/Flotation Data 31
6 Preliminary Disinfection Data 32
7 Variable Combinations Utilized For Flotation Testing 47
8 Summary of First Flush Data 49
9 Summary of Data At Intervals of Greater Than 4 Days Between Overflows 50
10 Summary of Extended Overflow Data 53
11 Particulate & Dissolved Relationships 53
12 Pollutant Removals by Screening 55
13 Pollutant Removals by Screening/Flotation 57
14 Summary of Particulate and Dissolved Organic Removal Efficiencies 60
15 Effect of Pressurized Flow Rate on Solids Removal 62
16 Comparison of The Effect of Overflow Rate on Removal Efficiencies 65
17 Summary of Disinfection Data 68
18 Operating Cost Estimates 80
19 Summary of Overflow Occurrence Data - 1971 94
20 Summary of Raw Water Quality Data - 1969-1971 95
21 Dissolved and Volatile Fractions In Combined Sewer Overflows 97
22 Operating Conditions For The Series Screening System 98
23 Summary of Overall Pollutant Removals Across The Screening System 99
24 Summary of Pollutant Removals on Various Screens 100
25 Variation in Hydraulic & Solid Loadings on The Screens 102
26 Wet Sieve Analysis Results on Storm 71-12 Raw Overflow 103
27 Comparison of Bench Scale and Full Scale Screening Data 105
28 Comparison of Pollutant Removal Efficiencies of 23 and 63 Micron Screens 106
29 Summary of Disinfection Data With Chlorine 109
30 Combined Sewer Overflow Characteristics - 1969-1973 120
31 Summary of Screened Water Quality - 1973 119
32 Pollutant Removals by Screening During Extended Overflows 122
33 Pollutant Removals by Screening/Flotation System in Split Flow & Effluent Pressurization at Low Overflow Rates 123
34 Screening/Flotation Effluent Quality - 1969-1973 124

List of Tables - (Continued)

Table Page

35 Summary of Operating Conditions, Microscreening Flotation Effluent 126
36 Summary of Wastewater Characteristics, Microscreen Treatment of Flotation Effluent 127
37 Summary of Pollutant Removals by Microscreening of Flotation Effluent 128
38 Summary of Operating Conditions For Microscreening Raw CSO 129
39 Summary of Influent and Effluent Characteristics For The Microscreening of Raw CSO 131
40 Comparison of Removal Efficiencies 132
41 Average Operational Parameters For Dissolved-Air Flotation Process - 1974 134
42 Combined Sewer Overflow Quality Characteristics - 1971-1974 135
43 Screened Effluent Quality Characteristics and Percent Removals by The Screening Process - 1971-1974 136
44 Percent Removals by The Dissolved-Air Flotation Process - 1971-1974 138
45 Final Effluent Quality Characteristics and Percent Removals by The Screening/Dissolved-Air Flotation Process - 1971-1974 139

A-1 Laboratory Analysis of Combined Sewer Samples Utilized For Chemical Oxidation Study 157
A-2 Results of Chemical Oxidation With Hydrogen Peroxide 162
A-3 Effect of UV Light and Cobalt on Hydrogen Peroxide Oxidation 163
A-4 Chlorine Oxidation Tests 165
A-5 Light Catalyzed Chlorine Oxidation 166
A-6 Oxidation With Combined Hydrogen Peroxide and Chlorine 168
A-7 Summary O_3 Oxidation Tests 169
A-8 Summary O_3 Oxidation and Air Flotation Tests 171
A-9 Summary Disinfection Data - All Spring Storms 172
A-10 Summary of Oxidation of Combined Overflows With Various Oxidants and Combinations 174

B-1 Hawley Road Field Data - 1972 185
B-2 Summary of Raw Water Quality Data - 1969-1972 186
B-3 Results of The Mixed-Media Filtration Tests 188
B-4 Upgrading of Flotation Effluents by Microscreening 189
B-5 Bench Scale Flotation Tests For The Evaluation of Effluent Recycle Mode of Dissolved Air Flotation (Without Activated Carbon) 191
B-6 Carbon Flotation Treatment - Storm No. 1972-1 193
B-7 Carbon Flotation Treatment - Storm No. 1972-2 194
B-8 Carbon Flotation Treatment - Storm No. 1972-3 195
B-9 Carbon Flotation Treatment - Storm No. 1972-4 197
B-10 Ozonation Tests 198
B-11 Results of Total Phosphate Analysis 200

List of Tables - (Continued)

Table		Page
E-1	Operational Data	211
E-2	Raw Waste Characteristics - First Flushes - 1969-1970 Data	215
E-3	Raw Waste Characteristics - Extended Overflows - 1969 Data	216
E-4	Screened Water Quality - First Flushes - 1969-1970 Data	218
E-5	Screened Water Quality - Extended Overflow - 1969 Data	219
E-6	Effluent Water Quality - First Flushes - 1969 - 1970 Data	221
E-7	Effluent Water Quality - Extended Overflow - 1969 Data	222
E-8	Dissolved COD and TOC Data - 1970 Data	225
E-9	Screen Backwash & Floated Scum Quality - 1969 Data	226
E-10	Screen Backwash & Floated Scum Quality - 1970 Data	228
E-11	First Flush Evaluations - 1969-1970	229
E-12	First Flush Removals in Percent - 1969-1970	231
E-13	Extended Overflow Removals in Percent - 1969 Data	232
E-14	Suspended Solids Mass Balance - 1969 Data	235
E-15	Screening/Flotation Pilot Unit Operational Data - 1971-1972	237
E-16	Raw Waste Characteristics Extended Overflows - 1971-1972 Data	238
E-17	Screened Water Quality Extended Overflow, 1971-1972 Data	239
E-18	Effluent Water Quality - Extended Overflow 1971-1972 Data- Low Overflow Rates	240
E-19	Effluent Water Quality - Extended Overflow 1971-1972 Data - High Overflow Rates	241
E-20	Floated Scum Qaulity - 1971 Data	242
E-21	Extended Overflow Removals in Percent 1971 Data - High Overflow Rates	243
E-22	Extended Overflow Removals in Percent 1971-1972 Data - Low Overflow Rates	244
E-23	Screening/Flotation Pilot Unit Operational Data - 1973	245
E-24	Raw Waste Characteristics Extended Overflows - 1973 Data	246
E-25	Screened Water Quality Extended Overflow - 1973 Data	247
E-26	Effluent Water Quality Extended Overflow, 1973 Data - Low Overflow Rates	248
E-27	Effluent Water Quality - Extended Overflow - 1973 Data - High Overflow Rates	249
E-28	Floated Scum Quality 1973 Data	250
E-29	Extended Overflow Removals in Percent - 1973 Data - High Overflow Rates	251
E-30	Extended Overflow Removals in Percent - 1973 Data - Low Overflow Rates	252
E-31	Operational Results - 1974 - Run No. 1	253
E-32	Operational Results - 1974 - Run No. 2	254
E-33	Operational Results - 1974 - Run No. 3	255
E-34	Operational Results - 1974 - Run No. 4	256
E-35	Operational Results - 1974 - Run No. 5	257
E-36	Operational Results - 1974 - Run No. 6	258
E-37	Operational Results - 1974 - Run No. 7	259
E-38	Operational Results - 1974 - Run No. 8	260
E-39	Operational Results - 1974 - Run No. 9	261

List of Tables - (Continued)

Table		Page
E-40	Operational Results - 1974 - Run No. 10	262
E-41	Operating Conditions For The Series Screening System	263
E-42	Raw Waste Characteristics	265
E-43	Screened Water Quality - Drum Screen 1 (20 Mesh)	267
E-44	Screened Water Quality - Drum Screen 2 (100 Mesh)	268
E-45	Screened Water Quality - Drum Screen 3 (230 Mesh)	269
E-46	Screen Backwash Quality	271
E-47	Operating Conditions For The Microscreening System	272
E-48	Microscreening Treatment of Flotation Effluent - (Raw Waste Characteristics)	273
E-49	Microscreened Water Quality - (Flotation Effluent Treatment)	274
E-50	Microscreening Treatment of Raw CSO - (Raw Waste Characteristics)	275
E-51	Microscreened Water Quality - (Raw CSO Treatment)	276

LIST OF FIGURES

NO.		PAGE
1	Relationship of frequency of combined sewer overflows to interceptor capacity	9
2	Project drainage area	21
3	Relationship of runoff coefficient to perviousness	22
4	Relation between water depth and flow in Hawley Road sewer	24
5	Typical interceptor device	25
6	Comparison Tyler mesh to size of opening	28
7	Scale drawing of demonstration system	35
8	Demonstration system	36
9	Screening system	37
10	Screening system	38
11	Flotation system	41
12	Flotation tank	42
13	Hawley Road outfall	44
14	Interior views of the control shack	45
15	Relationship between flow in sewer and suspended solids	52
16	Suspended solids removal-screening/flotation	58
17	Baffle arrangement for overflow rate tests	63
18	Recommended screen arrangement	73
19	Recommended screening/flotation arrangement	76
20	Overall system configuration	78
21	Schematic flow sheet for sequential screening treatment system	82
22	Sequential screening demonstration system	83
23	Sequential screening demonstration system	83
24	Open end of the screen	85
25	Liquid level electrical probes	85
26	Screening system	86
27	Raw feed system	88
28	Interior view of the control shack	89
29	Bench scale screening data	107
30	Modifications to dissolved-air flotation system	112
31	Schematic flow diagram for sequential screening system	113
32	Dissolved-air flotation & microscreening operation modes	115
A-1	Human tolerance for ozone	150
A-2	Ozone absorption systems	153
A-3	Schematic of ozone test apparatus	160
B-1	Screening/flotation flow diagram	180
B-2	Schematic of ozone test apparatus	183
D-1	Microscreen bench test apparatus	210

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Mechanical design and supervision of fabrication, construction and installation of the initial screening/flotation and sequential screening systems as well as subsequent modifications was carried out by the Design and Construction section headed by Joseph E. Milanowski.

Field operation of the Hawley Road pilot demonstration systems during over one hundred storm events, quickly responded to at all hours of the day and night, was performed by such dedicated individuals as Donald G. Mason, Mahendra K. Gupta, Frank Toman and Thomas L. Meinholz.

Timely completion of the laboratory analyses for the inevitable onslaught of samples resulting from each overflow treated was consistently achieved by Richard E. Wullschleger and his laboratory staff.

This document is a compilation and condensation of several individual reports previously prepared for EPA by various authors including Donald G. Mason (Sections IV - VII and Appendix A), Mahendra K. Gupta (Sections IV - X and Appendix B) and Michael J. Clark, Thomas L. Meinholz and Charles A. Hansen (Section X, Powdered Activated Carbon Addition). This document, Volume I, was compiled, condensed and edited by Anthony Geinopolos using the individual reports prepared by the above listed authors.

The cooperation of the City of Milwaukee in making the Hawley Road site available for these studies is duly acknowledged.

The bench scale study reported in Appendix B, Application of Activated Carbon Addition, was performed under the sponsorship of the Wisconsin Department of Natural Resources.

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SECTION I

CONCLUSIONS

1. Screening/Flotation Treatment

a. A screening/flotation treatment system is an effective method of reducing the pollution caused by combined sewer overflows.

b. The combined sewer overflows monitored had the following characteristics in mg/l at the 95% confidence level.

BOD	49±10
COD	161±19
Suspended Solids	166±26
Volatile Suspended Solids	90±14
Total Nitrogen	5.5±0.8

c. Approximately 20% of the overflows monitored exhibited first flushes of the following characteristics in mg/l at the 95% confidence level.

BOD	186±40
COD	581±92
Suspended Solids	522±150
Volatile Suspended Solids	308±83
Total Nitrogen	17.6±3.1

When present these first flushes persisted for 20 to 70 minutes.

d. All first flushes occurred at a time interval of greater than 4 days between overflows.

e. It was demonstrated that a screening/flotation system could achieve the following percent removal efficiencies based on the raw waste characteristics encountered (Hydraulic Loading: Screen 40 gpm/sq ft, Flotation 2.75 gpm/sq ft).

	Without Chemical Flocculant Addition	With Chemical Flocculant Addition
BOD	35±8	60±11
COD	41±8	57±11
Suspended Solids	43±7	71±9
Volatile Suspended Solids	48±11	71±9
Nitrogen	29±14	24±9

f. The chemical flocculant addition required to achieve the above stated removals was 20 mg/l ferric chloride and 4 mg/l of a cationic polyelectrolyte.

g. An operating pressure of 50 psig and a pressurized flow rate of 20% of the raw waste flow provided sufficient air bubbles for proper flotation tank operation.

h. The average volume of waste residual solids (*i.e.* screen backwash and floated scum) was 1.75% of the raw flow.

i. The average removal efficiencies for the screening/flotation system decreased (as shown below in percent removals) when the hydraulic overflow rate was increased from ~2.75 to 3.75 gpm/sq ft.

	Low Overflow Rate	High Overflow Rate
BOD	59	52
COD	57	54
Suspended Solids	70	61
Volatile Suspended Solids	71	64

j. Utilizing a 50 mesh (297 μ) screen at a hydraulic loading of 40 gpm per sq ft of screen. The percent removal efficiencies for screening alone were observed to be:

BOD	27 ± 5
COD	26 ± 5
Suspended Solids	27 ± 5
Volatile Suspended Solids	34 ± 5

k. The screening/flotation system provides sufficient detention time (~15 min.) for effective chlorination.

l. Because of the intermittent operation and remote location of combined sewer overflow treatment systems, completely automated operation is required.

m. The use of a 50 mesh (297 μ) screen eliminated the need for bottom sludge scrapers.

n. It was not always possible to obtain optimum chemical flocculant addition due to widely varying raw waste characteristics.

o. Bench scale tests showed that the effluent quality of screening/flotation treatment of combined sewer overflows could be upgraded significantly by using filtration, microscreening, powdered activated carbon and coagulants and the effluent recycle mode of dissolved-air flotation. However, when applied on the 5 mgd screening/flotation facility at the Hawley Road site, it was observed that,

(1) No apparent differences in removal efficiencies were obtained

as a result of using effluent recycle mode of pressurized flow as opposed to the split flow mode using chemicals.

(2) Suspended solids levels in the flotation effluent were reduced by 5-10% by microscreening based on raw effluent quality.

(3) The improvement in performance due to activated carbon addition was not readily apparent, and any improvement achieved did not appear to warrant the additional carbon costs incurred.

2. The sequential screening treatment system investigated was much less effective than the screening/flotation treatment system in handling combined sewer overflows. In fact, it was concluded that the use of three screens in series did not show any advantage over a single screen.

It was found that the screening system could achieve the following percent removal efficiencies based on the raw waste characteristics encountered (hydraulic loadings: 15-45 gpm/sq ft).

	Without Chemical Flocculant Addition	With Chemical Flocculant Addition
Suspended Solids	28 ± 8	22 ± 14
Volatile Suspended Solids	32 ± 11	31 ± 17
BOD	28 ± 7	16 ± 15
COD	30 ± 9	10 ± 7
TOC	25 ± 12	12 ± 17

3. The microscreening of raw CSO removed only about 35-57% of the suspended solids present in the overflows monitored during the 1973 season and no improvement in the effluent quality was achieved via microscreening compared to screening/dissolved-air flotation treatment.

4. Chemical oxidation bench scale studies indicated that chemical oxidation of combined sewer overflow is not technically or economically feasible. Chlorine, hydrogen peroxide and ozone, singly and in combination were the oxidants investigated.

SECTION II

RECOMMENDATIONS

1. Screening/flotation should be utilized to reduce the pollution from combined sewer overflows where treatment is the preferred alternative.

   Basic design and operating procedures have been outlined in this report and may be used in applying screening/flotation treatment full scale in handling combined sewer overflows.

2. There is a need for an investigation to determine and evaluate various sludge disposal alternatives for handling the residual sludges arising from screening/flotation and from other CSO treatment alternatives.

3. It is estimated that the Hawley Road test facility could be operated about 1% of the time for treating combined sewer overflows. This low magnitude of operating time is typical for facilities designed for treating only CSO. Consideration should be given to adapting CSO treatment processes, such as screening/flotation, for dual treatment of dry and wet weather flows.

SECTION III

INTRODUCTION

During recent years combined sewer overflow has been recognized as a significant pollution problem. Immediate reaction was to separate the sewer systems. It was found, however, that this solution was expensive and sometimes impossible. Furthermore, it has also been shown that stormwater could carry a large pollutional load, therefore, tending to reduce the effectiveness of sewer separation. As research to find a solution to the combined sewer problem began, it became apparent that no one solution would solve all the problems associated with combined overflows. The ultimate solution depends upon successful application of many different approaches which may include separation of sewers, holding tanks, and treatment systems.

The Environmental Protection Agency (EPA) has not only established combined sewer overflow (CSO) as a problem but has fostered technology research, development and demonstration to counteract it. This project illustrates well the continued efforts of EPA for the advancement of approaches for combined sewer overflow control and treatment. For example, from 1967 through 1974, EPA awarded grants and contracts for the bench scale investigation, pilot plant demonstration development and full scale installation of screening/flotation as a combined sewer overflow treatment method.

This volume, Volume I, covers the bench scale investigations and pilot plant demonstration development of screening/flotation as a CSO treatment method under EPA Contract No. 14-12-40. In a separate document, Volume II, is covered the full scale screening/flotation operation conducted under EPA Grant No. S800744 (formerly 11023FWC).

Initially, the technical approach in this project (EPA Contract No. 14-12-40) was screening and chemical oxidation of combined overflows. Early during the study it was determined that chemical oxidation was not feasible and this approach was abandoned. A summary of the work done on chemical oxidation may be seen in Appendix A. During the investigation of chemical oxidation, however, a promising alternative was uncovered. It was discovered that the pollutants in combined sewer overflow consisted mainly of particulate matter. This clearly indicated that an efficient solids/liquid separation process should provide a high degree of treatment for combined overflows. The work scope of EPA Contract No. 14-12-40 was modified to allow study of a screening/dissolved-air flotation system. Later, after evaluating the system for a short time, it became apparent that a more detailed study of the screening process could provide important additional information and the contract was amended to include those studies. Still later, promising improvements of the screening/flotation treatment method were investigated, as a part of the contract, on a bench scale and pilot demonstration basis.

In effect, the total work performed under EPA Contract No. 14-12-40 included the following:

1. Literature search, site arrangements, preliminary investigations
2. Design and construction of a 5 MGD screening/flotation system
3. Operation of the screening/flotation system
4. Design and construction of a 5 MGD series screening system
5. Operation of the series screening system
6. Upgrading screening/flotation performance by:
    a. Using flotation effluent pressurized flow as opposed to split flow pressurization
    b. Microscreening of flotation effluent
    c. Powdered activated carbon addition
7. System disassembly and restoration of demonstration site

This report, Volume I, summarizes the work performed to date on items 1 through 6, listed above.

SECTION IV

LITERATURE SEARCH

It is assumed that the following process elements will be utilized to accomplish the treatment of combined sewer overflows.

A. Solids/liquid separation

  1. Screening
  2. Dissolved-Air Flotation

B. Disinfection of the waste flow

A search of the existing literature was made to determine the characteristics of combined sewer overflow, and to obtain pertinent information on the above mentioned process elements.

CHARACTERISTICS OF COMBINED SEWER OVERFLOWS

More than 1400 U.S. communities serving 50 million people have what is known as combined sewer systems which provide one collection system for both sanitary sewage and stormwater runoff (1). During dry weather the flow in such a system consists mainly of sanitary sewage and is normally intercepted by the interceptor systems before it reaches the outfall, where it otherwise would be discharged to a lake or river. As long as the capacity of the interceptor system exceeds the flow in the combined sewer, the flow is directed to the sewage treatment plant for purification.

During a storm, the flow in the combined sewer can increase from 50 to 100 times the normal dry weather flow (2). Normal interceptor capacities are between 1.5 and 5.0 times the dry weather flow (hereinafter abbreviated DWF) (2)(3)(4). This would mean that at normal interceptor capacities, the interceptors would be from 97.3 to 99.0% efficient in collecting and transporting the sanitary sewage to the treatment plant. These efficiencies are very misleading, since during periods of high stormwater runoff, it is possible to have up to 96% of the sanitary sewage bypassing the interceptor system and being discharged untreated into the receiving waters (5). This discharge of untreated combined overflows could cause severe pollution problems if the water is reused a relatively short distance downstream as a water supply or for recreational activities.

The pollution caused by combined sewer discharge is directly related to the frequency of storm runoff exceeding the interceptor capacity. Three independent investigators (5)(6)(7) report that the normal dry weather flow is approximately equivalent to a rainfall intensity of about 0.01 inch/hour. With interceptor capacities of 1.5 to 5 times the dry weather flow, rainfall intensities greater than 0.015 to 0.05 inch/hour would be necessary to cause combined overflow which would go untreated. Palmer (6), Johnson (7), and McKee (5) studies the rainfall records of Detroit, Washington, D.C. and Boston. The results of their findings showing the number of combined overflows per month for given interceptor capacities may be seen in Figure 1. With an interceptor capacity of 5 times (DWF), the number of overflows per month was between four and six. This indicates the extent of possible pollution of the receiving body of water.

The pollutional effect of combined sewer overflows will, of course, be determined not only by the frequency of overflows, but also by the quality of the overflow. The most important and commonly discussed pollutional parameters associated with combined sewer overflows are suspended solids, BOD, and coliform count. To establish a basis for comparison, the average raw (primarily domestic) sewage contains 200-300 mg/l suspended solids (1)(8)(9), (50-60% of these suspended solids are settleable), 100-300 mg/l BOD (1)(8)(9) and coliform counts of 43-150 x 10^4 per ml (9)(10).

Assuming pure stormwater to be essentially unpolluted, it would be expected that the BOD, suspended solids, and coliform counts of combined sewer overflow to be substantially lower than those of raw sewage. This assumption could result in considerable error when estimating the quality of combined sewer overflows. A limited amount of data has been obtained which indicates the quality of pure storm runoff is highly variable and can be quite polluted (4) (6)(11)(12)(13)(14). BOD's ranging from 6 to 600 mg/l, suspended solids ranging from 100 to 2000 mg/l, and coliform counts as high as 200,000 per ml have been reported.

Another factor which can greatly influence the quality of combined sewer overflow is the amount of solids which settle in the sewer system during periods of low flow. Since combined sewer systems must be designed for a wide range of flow, the amount of solids which are deposited during periods of dry weather can be significant (15)(16)(17). Hopefully, these solids will be resuspended during the first flushes of the storm and be intercepted before combined overflow begins. Published data has shown, however, that with an interceptor capacity of only 1.5 to 5 times the dry weather flow and a sewer system designed to take 50 to 100 times the dry weather flow, most of the solids which have settled are not resuspended until after the capacity of the interceptors has been exceeded (11)(14)(15)(16)(17). Hence, these solids can contribute greatly to the pollutional load in the stormwater overflow.

The above discussion has illustrated that combined sewer overflows can contribute a significant pollutional load to receiving streams and lakes. Table 1 summarizes data reported by others on the quality of combined sewer overflows. It is obvious that the quality of combined overflows is highly variable. Of the three pollutional parameters most mentioned, BOD, suspended solids, and coliform count, the latter, a measure of pathogenic bacteria contamination (8), appears to be the most significant (10)(13). In a recent study (13), a survey was made to indicate what water uses were most affected by combined

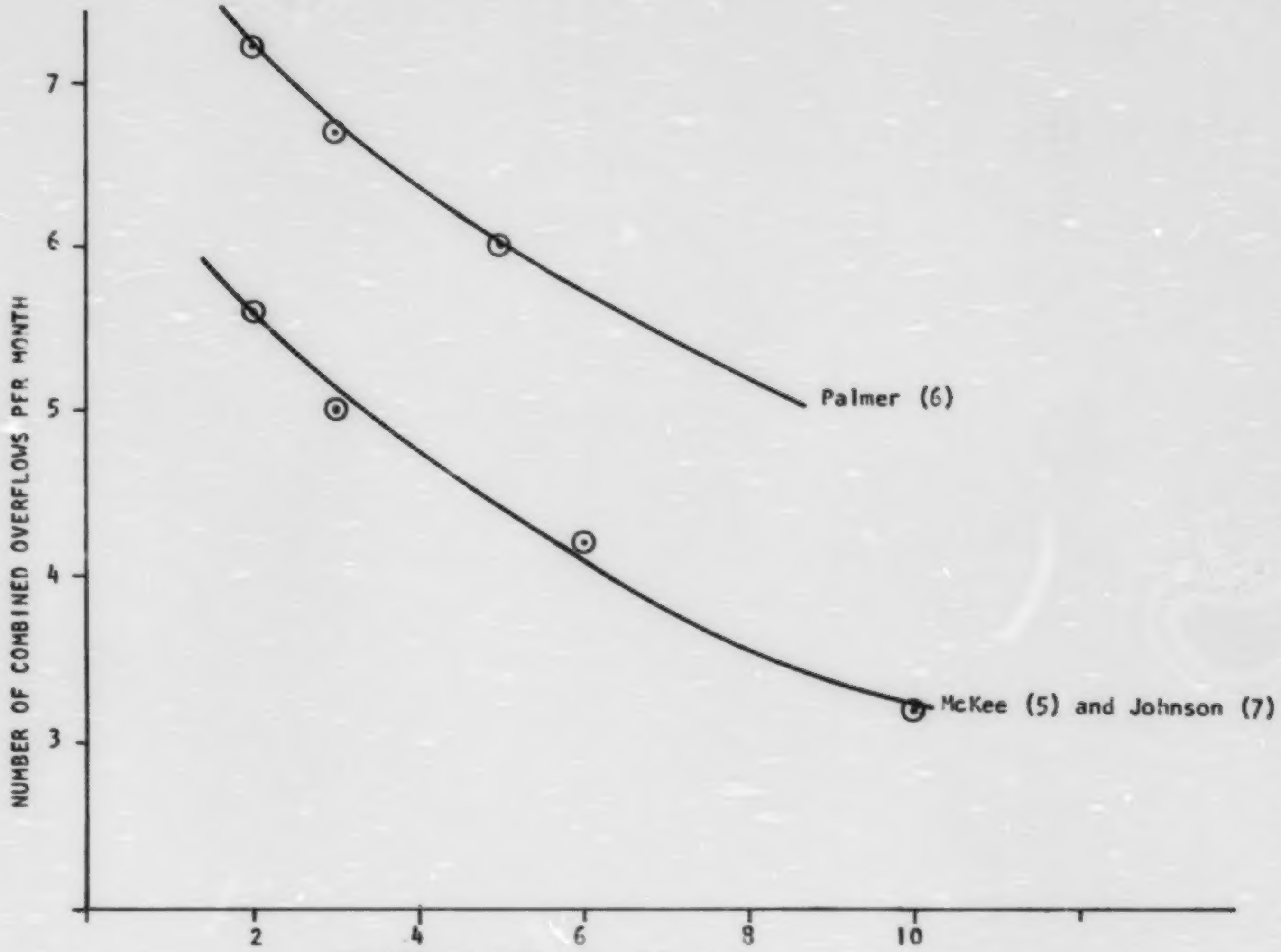


Figure 1. Relationship of frequency of combined sewer overflows to interceptor capacity

Table 1. QUALITY OF COMBINED SEWER OVERFLOWS

Source reference number	BOD, mg/l	Suspended solids, mg/l	COLIFORM, per ml $\times 10^3$	Discussion
(6)	50	250	43	Detroit, Michigan
(14)	100	544	--	Buffalo, New York (Bird Avenue)
(13)	59	203	300	San Francisco, California (Average value)
(13)	92	129	.5	Chicago, Illinois
(13)	121	436	--	Buffalo, New York (Bailey Avenue)
(12)	--	150	180	Average values
(11)	40 to 260	130 to 930	2.3 to 24	Toronto, Ontario, Canada (Eglinton Avenue)
(11)	220 to 614	168 to 426	2.1	Welland, Ontario, Canada (Burgar Street)

overflows. The survey indicated those uses most affected were commercial (fishing), recreational (swimming), and public health (water supplies). The main pollutant affecting these water uses is pathogenic bacterial contamination (measured by coliform density) (1)(5)(15)(16). Table 1 shows the range of coliform counts to vary from 0.5×10^3 to 300×10^3/ml in combined sewer overflows. The suspended solids concentration of combined overflow can be quite large. Table 1 shows a range of suspended solids in combined overflows of 129-930 mg/l. The values shown in Table 1 are averages. The initial peak of suspended solids can be higher (11)(15)(14). Romer and Klashman (16) presented graphs which illustrate how suspended solids in combined overflows vary as the flow increases. They reported that, in general, the suspended solids concentration and the flow reach a maximum value at approximately the same time. The suspended solids then begin to fall off rapidly. Stegmaier (17) has shown that the main increase in solids is of inorganic nature. Initially, the BOD exerted by the solids will probably be quite large, since the settled organic material will be resuspended before the inorganics. Hence, the BOD of combined sewer overflows will initially be quite high with a large portion of the BOD in the particulate form. This would seem to indicate some sort of mechanical separation may be very effective in removing BOD during the first flushes of a storm. Later, as the storm progresses the BOD would be expected to decrease to levels much lower than those of raw sewage. The ratio of dissolved to particulate BOD will increase and mechanical separation will probably become less efficient in removing BOD.

REMOVAL OF SOLIDS BY SCREENING

Bar screens with openings of 1/2 to 1-1/2 inches are used extensively in sewage treatment plants throughout the United States (18). The amount of solids removed by these coarse type screens ranges from 0.5 to 6 cubic feet of wet solids per million gallons of sewage (19)(20). On a dry weight basis, this represents 9 to 48 pounds of dry solids per million gallons of sewage (19)(20) or a removal of about 1-6 ppm from the sewage flow. Since raw sewage contains 200-300 ppm (1)(8)(9) suspended solids, bar screens remove only a small fraction of the solids, i.e. 0.5 to 2%. This fact is not surprising, since the primary purpose of bar screens is to remove large and/or floating solids to protect pumps and other treatment devices downstream of the bar screens (8)(18).

In general, the approach velocity in the screening channel should not fall below a self-cleaning value (about 1.25 fpm) or should it rise to values high enough to force the screenings through the bars (about 3 fps) (8)(18). Head-losses through the bar racks can be formulated as an orifice loss (8).

$$h = \beta(w/b)^{4/3}\, h_u \sin\theta$$

where: h = loss of head in feet
w = maximum width of the bars facing the flow
b = minimum width of the clean openings between pairs of bars
h_u = velocity head (in feet) of the water as it approached the rack
θ = the angle of the rack with the horizontal
β = bar shape factor

Values for β are 2.42 for sharp-edged rectangular bars, 1.79 for circular bars, and 0.76 for tear-drop shaped bars (8). Headloss through bar racks is generally held below one foot by periodic cleaning of the bars. This cleaning can be accomplished manually or mechanically (8).

Fine screens of 1/16 inch to 1/32 inch openings have been used in a number of locations (19)(20(21)(22) to treat municipal wastes. This size of screen will removed 2-20% of the suspended solids in raw sewage (9)(18)(19)(20)(21)(22). Openings of 1/16 inch correspond to a sieve size (Tyler series) of 12 to 20 mesh. Use of standard wire sizes finer than these meshes tend to blind because of the build-up of animal fats and greases on the screen (23). It has been reported by Peterson (23), however, that the use of new synthetic materials for screens has greatly reduced the blinding tendency and allows greases to be discharged from the top of the screens. He also reports meshes as fine as 300 have been used when filtering raw sewage. The allowable rates of filtration, with these extremely fine mesh screens, however, were not reported. The results of screening raw sewage through a 300 mesh screen showed a reduction in suspended solids from 196-101 mg/l or a 48.5% removal (23). This removal rate is approximately equal to the rates obtained by primary sedimentation of raw sewage (8)(18).

As the openings in the screen are reduced, the headloss increases and screen blinding becomes very important. This necessitates automatic mechanical cleaning, which is generally accomplished by backwashing the screen with jets of water and/or air. Headlosses through fine screens can be calculated from an orifice type equation.

$$Q = CA\sqrt{2gh}$$

where:

Q = flow (cfs)
A = area (sq ft)(actual open area)
g = gravity constant (32 ft/sec^2)
C = screen coefficient
h = headloss through the screen (feet)

Screen coefficients (C) vary with the size of the screen openings. Values are generally between 0.3 to 0.6 for 2 to 60 mesh screens. Headlosses through fine mesh screens are generally held below 2.5 feet (8) by varying the frequency of cleaning.

There is a very limited mention found in the literature on screening of combined sewer overflows. Stegmaier (17) and Romer and Klashman (16), however, have shown that a large portion of the suspended solids in combined sewer overflows can be attributed to inorganic materials. This tends to indicate that fine screening of combined sewer overflows may show a higher percentage of removal of suspended solids than is obtainable when screening raw sewage. Boucher and Evans (24) have discussed the microstraining process and its applications in removal of suspended material. They have indicated that miscoscreening can be effectively and economically used in polishing of sewage effluents. The Metropolitan Sanitary District of Chicago is reported to be using microstrainers for its Hanover Water Reclamation Facility.(25). A study by Kellbaugh et al (26) reported up to 98% of suspended solids were removed from a combined sewer overflow by using a nominal 23 micron aperture microstrainer screen. However, most of the data published towards the use of microstrainers in waste treatment has been of investigational nature only, and significantly more data is needed to substantiate such findings.

DISSOLVED-AIR FLOTATION

An active use of dissolved-air flotation (DAF) in the waste treatment area has only been made in the last two decades, but the use of air-bubbles to change the apparent specific gravity of suspended matter in water has been practiced for nearly a century in the mining industry for the processing of ores. Selective adsorption was accomplished by the use of flotation agents. Chase (27) and Rohlich (29) have discussed the developmental background of dissolved-air flotation. The process as it is used now is an outgrowth of air flotation methods used in the recovery of paper fibers. The fiber recovery was achieved by the adsorption of an air bubble on the fiber. The floated material formed a scum and was collected by a suitable mechanism. The presence of alum and glue addition aided the separation of fiber by the flotation process. Dissolved-air flotation utilizes a much smaller diameter bubble (less than 100 microns) than that used in the mining industry. It is clear from the above discussion that the removal of suspended matter is accomplished when there exists sufficient adsorption forces between the air bubble and solid particle.

Geinopolos and Katz (29) have discussed solids-liquid separation by dissolved-air flotation as compared to sedimentation and have indicated that a waste could be treatable by either sedimentation or flotation, but higher separation rates and solids concentration may be possible by dissolved-air flotation. This results in smaller basins, smaller sludge volumes and higher water recoveries for treatment by flotation processes as compared to sedimentation. The mechanism and driving forces involved in the flotation process are similar to those encountered in sedimentation. Stoke's Law illustrates the mechanism by the following equation:

$$V = gD^2(\gamma_s - \gamma_l) / 18\mu$$

Where:

V = Particle separation velocity, ft/sec
g = Gravity constant, ft/sec^2
D = Diameter of particle, ft
γ_s = Density of particle, lb/cu ft
γ_l = Density of liquid, lb/cu ft
μ = Viscosity of liquid, lb/ft/sec

In the flotation process, the density of the air-solid combination is less than the suspending medium and value of V becomes negative, causing an upward particle velocity. Also, the effect of the air-bubble is to increase the difference in densities between the particle and suspended medium, which in turn increases the solids separation rate.

Van Vuuren et al (30) has reported the use of oxygen produced by algal photosynthesis to accomplish flotation. He also cited the applicability of dispersed air flotation in conjunction with chemical precipitation in advanced treatment of wastes (31). Chase (27) has described the types of dissolved-air flotation processes used for waste treatment. These include pressure and vacuum types. However, pressure type applications in waste handling far outnumber those for vacuum flotation, primarily because of inherent flexibility in a pressurized system. The vacuum process is limited by the amount of reduced pressure that can be effectively used. Gelnopolos and Katz (29) state that the process elements of dissolved-air flotation are:

(1) Flow pressurization
(2) Air introduction
(3) Air solution
(4) Pressure reduction and bubble formation
(5) Bubble/solids attachment
(6) Solids/liquid separation
(7) Separated solids removal

The literature described variations in the flow pressurizing process (27)(28)(32)(33). These include: total pressurization, in which the entire volume of raw waste is pressurized, split flow, in which a portion of the raw waste is pressurized and later blended with the remaining raw waste stream; and effluent pressurization, in which a portion of basin effluent is pressurized and later blended with the entire volume of raw waste.

The dissolved-air flotation process has been applied to remove suspended matter from many industrial wastes such as: paper wastes (35), refinery wastes (28)(36), laundry wastes (37), soap wastes (38), machine shop wastes (39), automobile wastes (40), and others (27)(28) prior to discharge in a receiving body of water or resue. Vrablic (34) in his discussion of the fundamental principles of dissolved-air flotation mentions that hydrophobic solids will float much more easily than will hydrophilic ones. In an investigation of the kinetics of removal of organic matter by activated sludge, Rohlich and Katz (41) demonstrated that activated sludge floc can be separated from water by dissolved-air flotation. Ettelt (42) has also shown that dissolved-air flotation can be successfully employed for activated sludge thickening. There have been several other reports on the use of dissolved-air flotation for dewatering of aerobic biological solids (43)(44)(45)(46).

Proper performance of a flotation unit is dependent upon sufficient air bubble/solids attachment to effect good flotation. Batch laboratory flotation tests as described by Eckenfelder (47) have been used to estimate the flotation characteristics of wastes for the purposes of design. Howe (48), in a mathematical derivation of flotation cell design also recommended that considerable experimentation with each different waste precede the use of his equations in determining the exact criteria for flotation cells. For sludge thickening application, air/solids ratio has been used to relate laboratory data to prototype facilities. A ratio of 0.03-0.10 is considered optimum for most sludges (34)(49). However, air/solids ratio for clarification alone is generally not critical. Truck mounted continuous flow, pilot scale units are used widely to obtain design information. Primary variables for flotation design are operating pressure, pressurized flow to raw waste flow ratio, retention period and the combined particle/air bubble rise rate. Generally, the effluent suspended solids decrease and the concentration of solids in the floated sludge increase with increasing retention period. For clarification, a detention period of 15 to 30 minutes is normally considered adequate in the flotation zone. Rise rates of 1.0 to 3.0 gpm/sq ft (0.13-0.39 feet/minute) are commonly employed. The amount of pressurized flow usually varies from 15 to 50% of raw waste flow for separation. The recycle amount and detention period are higher for thickening application depending upon feed solids concentration. The process pressure may vary from 30 to 70 psig, with 40 psig considered normal. Air requirements range from 0.5 to 1.0 cu ft of standard air per one hundred gallons of pressurized flow (32). The air and liquid are mixed under pressure in a retention tank with a detention time of 1 to 3 minutes.

Addition of chemicals may be employed depending upon the nature of the waste and the degree of treatment required. Chemicals such as alum, lime and ferric chloride are usually used in the chemical treatment of a wastewater. The purpose of chemical treatment is to precipitate and coagulate colloidal and finely suspended particles to form large suspended floc particles. This increases the separation rate of the solids by flotation. Recent efforts to improve flotation efficiency by chemical addition have involved use of synthetic organic polyelectrolytes. Generally these polymers have been found to improve solids capture (clarification), to increase the concentration of solids in the float and to increase the capacity of flotation equipment (50,51,52). An apparent advantage of polyelectrolytes is the elimination of a separate flocculation tank, since the floc particles are formed in an extremely short period of time. Cationic polyelectrolytes have been successfully employed as flotation aids for thickening applications (46)(53). The results indicate that desired float concentrations may be achieved with high solids loadings when polymers are utilized. Bench scale procedures are normally employed for determining the dosage and effectiveness of a particular polymer application in dissolved-air flotation.

DISINFECTION OF COMBINED SEWER OVERFLOWS

Disinfection may be defined as destroying those bacteria that cause infection or disease. Sterilization, achieved for example at 250°F and 15 psi for 15 minutes, is defined as the destruction of all living organisms (54). Methods commonly used for disinfection include heat, ultraviolet light, and chemical addition. Chemicals which have been used include chlorine, bromine, iodine, potassium permanganate and ozone (8). The various methods and chemicals used for disinfection which appear applicable to this project are discussed below.

Ultraviolet Light Disinfection

The effect of radiation on bacteria has been studied in detail, and the relationship between wave length and germicidal effect is well known. The optimum wave length is 2600 angstrom, hence, low pressure mercury vapor lamps with their high output at 2537 angstrom are effective bactericidal agents (55). Light of this wave length falls in the ultraviolet section of the light spectrum. To insure disinfection, the water should be relatively free of suspended matter which might shade the organisms against the light (8). Time and exposure intensity must also be adequate to insure disinfection. One hundred microwatts per square centimeter of 2537 angstrom light will produce high bacteria kills at contact times of less than one minute (55)(56).

Use of ultraviolet light for disinfection has found limited application, probably because other methods of disinfection are more economical (8).

Disinfection by Chemicals

Chlorine has proven so economical and efficient that it is widely employed for its bactericidal action. The chlorination of wastes may be regulated to accomplish various degrees of bactericidal action. Chlorine is a bacteriostatic agent when applied in small concentrations (2 mg/l), to prevent an increase in the bacterial population. Chlorine is a disinfecting agent when applied in larger amounts (10 mg/l) to destroy those bacteria that cause infection or disease. Chlorine may be, but seldom is, applied in amounts so large (2000 mg/l) as to be a sterilizing agent (i.e. to destroy all living organisms (54).

Forms of chlorine which may be used for disinfection and other purposes include gaseous or liquid chlorine, chlorinated lime, calcium hypochlorite, sodium hypochlorite, chlorinated copperas, and chloramines. Chloramines, however, are a slower acting and less active form of disinfectant. Liquid or gaseous chlorine is the most commonly utilized form.

The efficiency of disinfection using chlorine or other disinfecting agents is dependent on (a) the contact time, (b) the type and concentration of microorganisms, (c) the pH and temperature of the water, (d) the presence of interfering substances, (e) and the degree of protection afforded organisms from the disinfecting solution by materials in which they may be imbedded.

Generally, a chlorine dosage, sufficient to give a 0.5 ppm residual after a 15 minute contact time, is considered adequate for disinfection (54). The actual amount of chlorine added to obtain this residual will vary with the waste being chlorinated. Fair and Geyer (8) give values of 6 to 24 mg/l for raw sewage.

Camp (10) indicates screening and chlorination of combined sewer overflows would be an effective and inexpensive way of treating these flows. Chlorine dosages were estimated to range from 1.6 to 8.5 ppm.

Symons (57) found the chlorine demand for Buffalo sewage during periods of combined overflow to range from 6 to 7 mg/l. Considering the possible quantities of combined sewer overflow, this represents quite a substantial chlorine dosage, and will require chlorine feeders operating over a very wide range of flows.

Iodine and bromine were also found to be effective in disinfecting sewage, but required higher dosages (4-9 times) compared to chlorine (58). Fluorine was found to be so reactive that it was difficult to store and apply (58).

Potassium permanganate has been used to disinfect water supplies (59)(60), and is an effective disinfectant at relatively low dosages (59). Use of potassium permanganate has not been widespread. This is probably due to one or more of the following disadvantages of potassium permanganate disinfection when compared to chlorine disinfection.

1. $KMnO_4$ imparts a purple color to the water which must be removed before use (62).
2. Most effective pH for $KMnO_4$ is 5.9 which is below the pH of many water sources.
3. Potassium permanganate is not a good post-treatment disinfectant because of the color and pH criteria.

Ozone is a very effective disinfectant. This fact is well known and has been proven over a period of 60 to 80 years (35)(46)(61)(62)(63). Ozone is used extensively in Europe, especially in France (62). Disinfection by ozone follows a slightly different pattern when compared to chlorine. Generally, with increasing chlorine dosage the number of bacteria progressively decrease, while with ozone little reduction is noticed until a critical dosage is reached. At this critical value the bacterial population rapidly reduces (35).

Unlike chlorine, the disinfecting action of ozone is little affected by temperature changes or pH. Ozone acts rapidly and is almost instantaneous, where chlorine needs time to be effective (35)(61).

The reason ozone is not utilized to the same extent as chlorine is probably twofold, i.e., cost and inability to carry an ozone residual for any length of time. Hann (62) states that, in general, if disinfection is the sole objective, ozone is more expensive than chlorine. This is largely due to the sophisticated and expensive equipment required for on-site ozone generation. When using ozone as a disinfectant, the inability to carry an ozone residual for significant periods is cited as a disadvantage (35).

When using ozone, proper precautions must be taken in applying the ozone to insure disinfection (62). The water should be low in turbidity, the ozone demand must be satisfied, and there must be a residual of free ozone in the water for a definite period of time. This usually is from 0.1 to 0.2 ppm ozone residual for 1 to 5 minutes (35)(62).

SUMMARY REMARKS

The material contained in this literature search was compiled in an effort to uncover the known process elements applicable to the treatment of wastes similar to combined sewer overflows. The information gained from this literature search will be used as a guideline for laboratory and bench scale tests to determine what combination(s) of the various process elements is (are) best suited to the design, fabrication, and operation of a prototype combined sewer overflow treatment unit.

Although a literature search is technically concerned only with the reporting of data found in published form, some of this data, for one reason or another can be eliminated from further consideration without the benefit of laboratory testing. As a result, this report comprises a certain number of engineering judgments and/or evaluations. Such judgments, however, have been made only where the material available or the investigator's experience have justified making them. That data which appeared to have genuine value to the completion of this project has been carried forward to the laboratory studies portion of the project.

Significant observations from the literature search are summarized below:

1. The flow in combined sewers can increase 50 to 100 times the dry weather flow.
2. Normal interceptor capacities are between 1.5 to 5.0 times the dry weather flow.
3. Up to 96% of the sanitary sewage can bypass the interceptor system during heavy storms.
4. Rainfall intensity greater than 0.015 to 0.05 inches per hour is generally sufficient to cause combined sewer overflow.
5. Limited data indicate pure storm water can be quite polluted.
6. The majority of the solids settled in the sewer system during dry weather are not resuspended until the capacity of the interceptor system is exceeded.
7. It was indicated that the main water usages affected by combined sewer overflow were commercial fishing, swimming, and public water supply due to bacterial contamination.

SECTION V

SITE SELECTION AND PRELIMINARY INVESTIGATIONS

SITE SELECTION

A search was conducted to select a suitable demonstration site for the installation and operation of a demonstration treatment unit. The City of Milwaukee, as an available source of combined sewer overflow, was solicited in regard to participating in the demonstration of the proposed treatment system. The City of Milwaukee responded favorably by offering both access to a combined sewer as well as providing sufficient land to install the demonstration equipment. In addition, the City Engineer's Office was made available for consultation and aid in selecting the most beneficial demonstration site.

Six potential sites were investigated. These sites were located in the City of Milwaukee as follows:

1. The Edgewood Avenue site, consisting of a 72" combined sewer discharging into the Milwaukee River.
2. The 27th Street site (south end of viaduct), consisting of a 48" combined sewer discharging into the Menomonee River.
3. The East Kane Place site, consisting of a 72" combined sewer discharging into the Milwaukee River.
4. The Bay Street site, consisting of a 90 inch diameter combined sewer discharging into Lake Michigan.
5. The Russell Avenue site, consisting of a 90 inch diameter combined sewer discharging into Lake Michigan.
6. The Hawley Road site, consisting of an 8'6" by 5'0" combined box sewer discharging into the Menomonee River.

The potential sites were appraised and evaluated from the standpoint of availability for project duration, access to sewer flow, access to utility sources, space limitations, extent of structural and/or topographical modifications, proximity to residential or developed areas, drainage area covered, and the socio-economic nature of the drainage area.

By inspection, the Edgewood Avenue, 27th Street, and East Kane Place locations were eliminated as potential demonstration sites. The Edgewood Avenue and 27th Street sites were inaccessible and limited in space. The East Kane Pl. site was located in a residential and developed area. In fact, the site consisted of a city-owned lot, located between two residences, which were about thirty feet apart.

The Bay Street, Russell Avenue, and Hawley Road locations were further investigated as potential demonstration sites. Maps of the respective combined sewer areas were obtained from the City Engineer's Office in which the drainage area covered and the socio-economic nature of the drainage area were delineated. The areas drained by each of these three sites is predominantly residential with some local business and industrial activity. The drainage areas covered by the three potential sites were as follows:

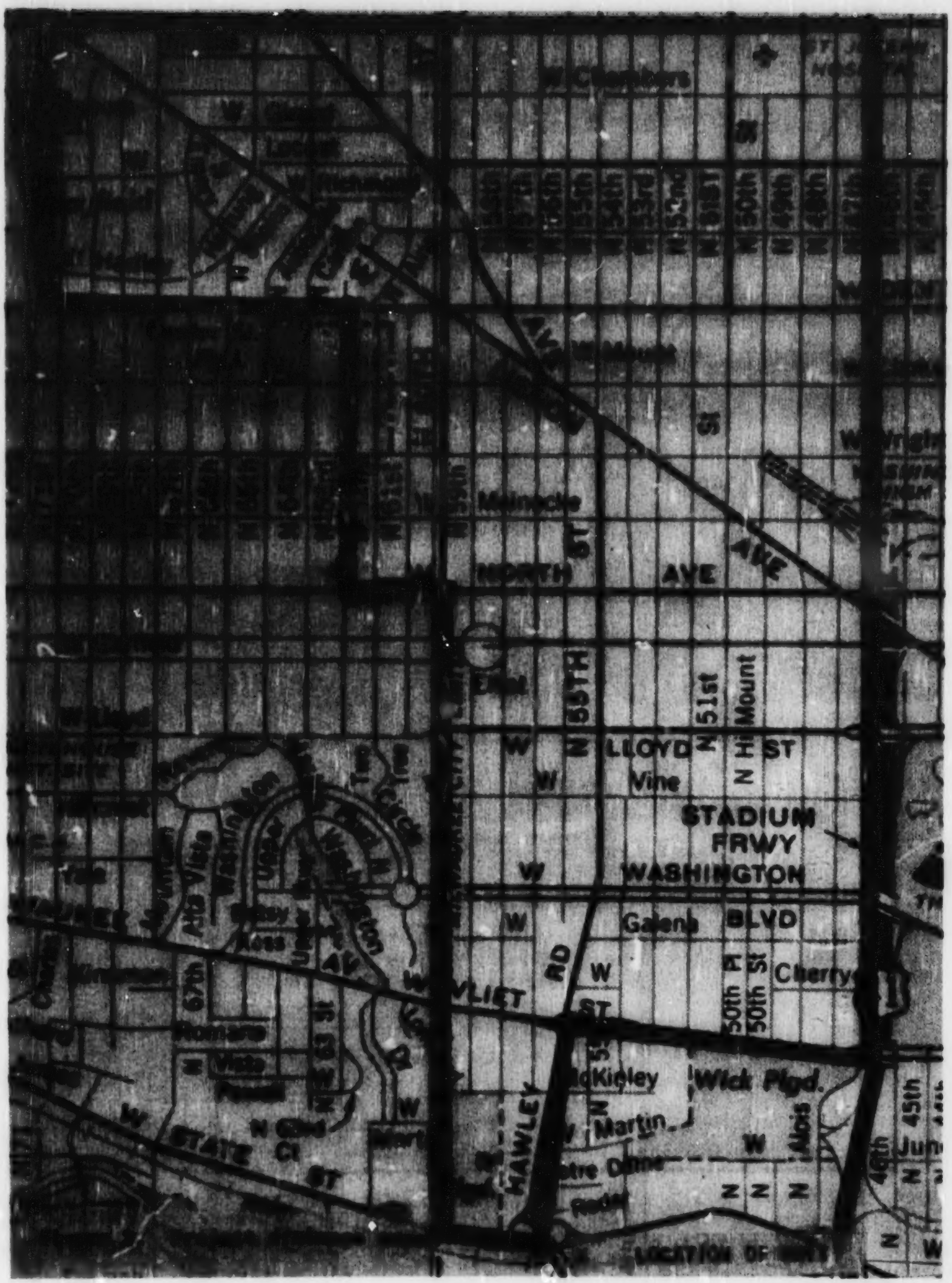
Bay Street	385 acres
Russell Avenue	465 acres
Hawley Road	495 acres

The Bay Street location was eliminated because an investigation revealed that it would be difficult and impractical to impound the flow in the sewer to provide the necessary raw sewage pump suction conditions.

The Russell Avenue site was eliminated because of a restrictive time limit placed by Milwaukee County authorities upon the use of the site for project purposes. It was felt that the site may not be available for the full duration of the project.

Since the Hawley Road site appeared to be the most desirable location for a demonstration unit, additional information was obtained on this sewer and the area served.

As mentioned above, the total area served by this sewer is 495 acres. The area is located on the western edge of the Milwaukee City limits. Figure 2 presents a street map of the City of Milwaukee. The outlined portion depicts the drainage area served by the Hawley Road sewer. The drainage area was studied using recent (1970) aerial photos. It was determined that approximately 42% of the area was impervious, i.e., roof tops, streets and parking lots. This value is within the range presented in the literature (8) for North American cities in areas of 1 and 2 family dwellings. The relationship between runoff coefficient and perviousness is presented in Figure 3. The data in Figure 3 is based on the City of Milwaukee runoff curves. It may be seen (Figure 3) that the runoff coefficient for the Hawley Road drainage area is 0.40. While it is recognized that the runoff coefficient can vary as the storm progresses (8), no attempt was made to refine the runoff coefficient since an exact number was not critical to this project. The aerial photograph indicated that the area is a completely developed residential area of one of the older sections of the city. There is very little open area present such as parks or fields. All dwellings are of the one and two family variety. Population density based on number of dwellings per acre and assuming four persons per family was estimated at 35 persons per acre. There are some small shops such as jewelry, hardware, etc. No industrial manufacturing facilities are located within the drainage area served by the Hawley Road sewer. The one industry which is within the drainage area is Topp Oil and Supply Company.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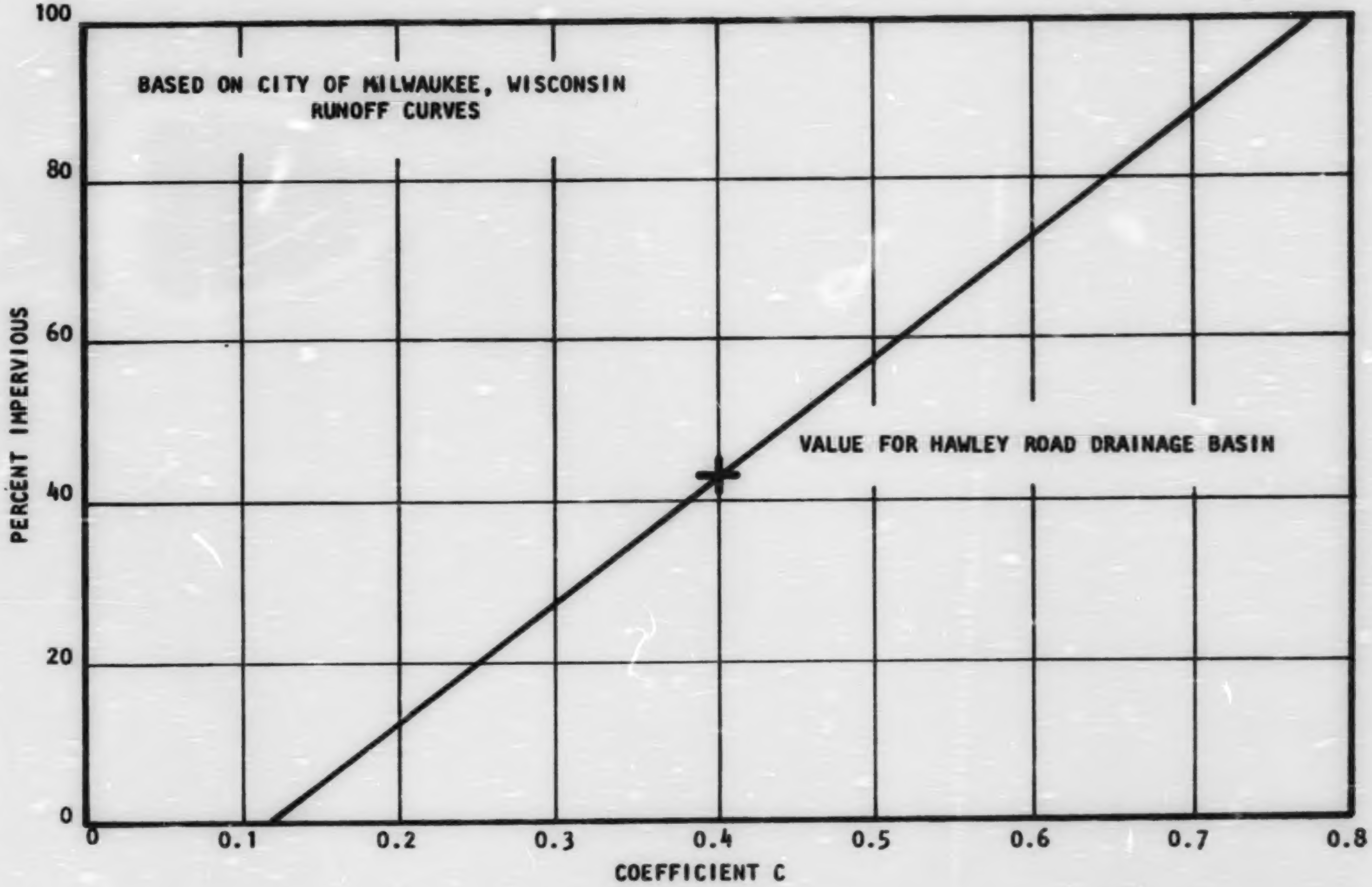


Figure 3. Relationship of runoff coefficient to area perviousness

They are involved with blending various oils and apparently do not actually process any oil at this site. A discussion with personnel at the Milwaukee Sewage Treatment Plant revealed that Topp Oil did not discharge any significant pollutional load into the sewage system.

The combined sewer outfall serving the Hawley Road drainage area is rectangular in cross section, 8.5 ft wide and 5 ft high. The relationship between water depth and flow rate is shown in Figure 4. It may be seen from the figure that the sewer has a capacity well in excess of 100 MGD. Because of the location of the sewer and the rectangular shape, a retaining structure was easily added to impound the flow. This allowed long test runs even during periods of low rainfall intensity. Calculations show that if a 3 foot high retaining structure is placed at the combined sewer outfall to retain the flow, a volume of about 100,000 gallons can be retained for evaluation after normal overflow has stopped. The retaining structure is a movable dam which tips up as a result of water pressure if the sewer begins to surcharge. In the normal untipped position the dam does not seal the sewer completely and this insures that the sewer will always be dry prior to any overflow. At a treatment rate of 5 MGD, this reservoir would allow an additional one half hour operation of the demonstration system. In actual operation an additional operating time of only 15-20 minutes has been realized. It should be noted that the length of operation reported herein includes this 15-20 minute storage factor and hence the duration of overflow is shorter than the length of run by this time period. The Hawley Road Sewer is fed by two interceptor devices. These interceptor devices are of the sump type. A sketch of the interceptor device utilized is shown in Figure 5.

Since the Hawley Road Sewer and adjacent land met all the requirements necessary to successfully complete the demonstration phase of this contract, arrangements were completed with the City of Milwaukee in February of 1968 to allow use of the sewer and land for this project.

PRELIMINARY INVESTIGATIONS

After the site selection was finalized, 14 overflows were monitored to obtain information on overflow characteristics, and to provide raw overflow for subsequent laboratory testing. Results of the laboratory testing program were then utilized to design the demonstration system. Table 2 presents a summary of the data collected prior to system design. As was expected, the range of values is quite large. Suspended solids values from 2158 to 65 mg/l were observed, and COD values ranged between 1410 and 52 mg/l. The dissolved organic fraction of the overflows as measured by COD was only 4 to 25% of the total organic load present in the combined overflow. This indicated that an efficient solids/liquid separation system should provide high removals of pollutants from the raw waste. Coliform density also varied widely from 440 to 26,000 per milliliter.

Laboratory testing which was performed included screening, chemical oxidation, flotation and disinfection. Chemical oxidation proved impractical for use in treating combined sewer overflow. Complete details of oxidants utilized, reaction times and efficiency may be seen in Appendix A.

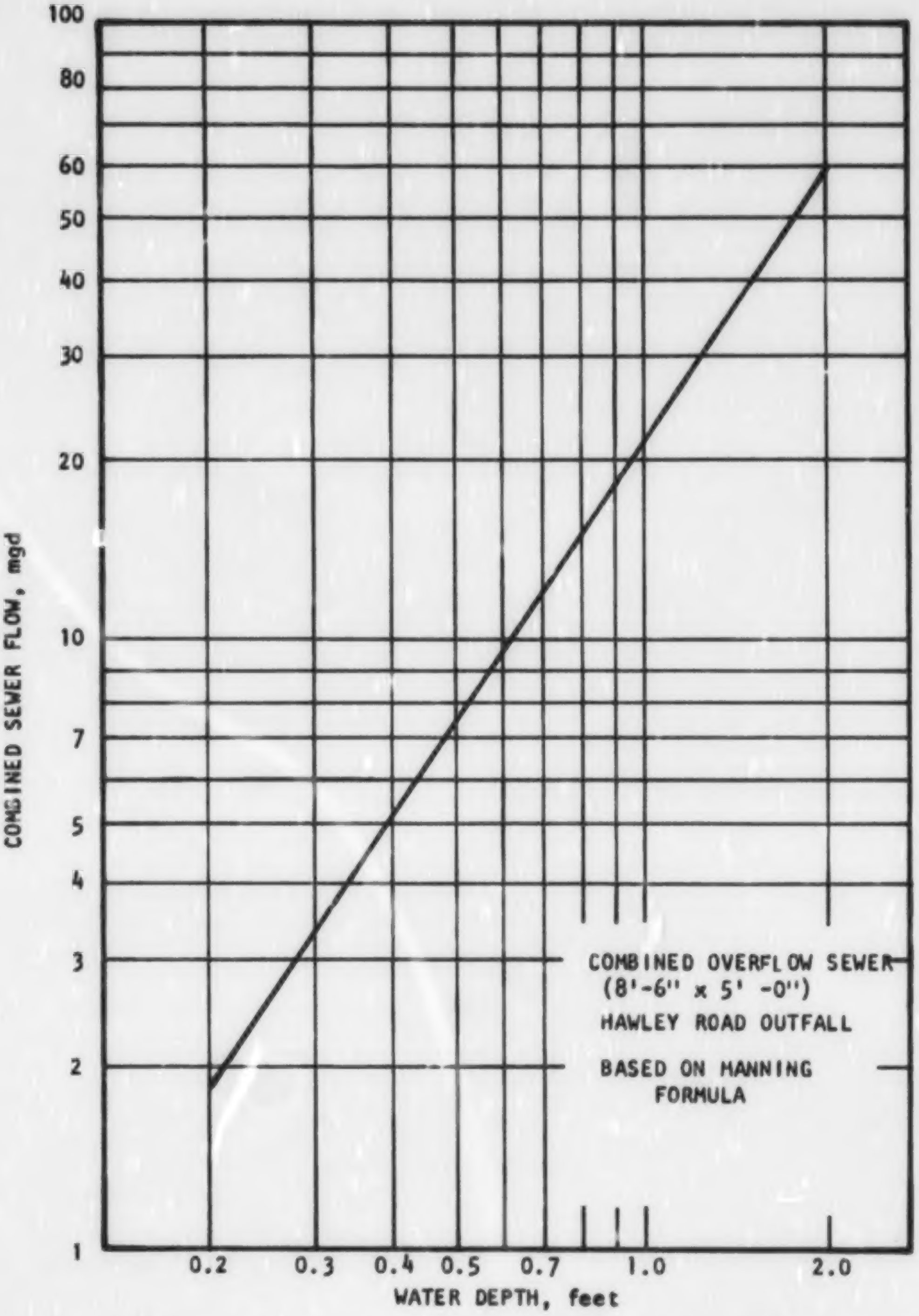


Figure 4. Relation between water depth and flow in Hawley Road sewer

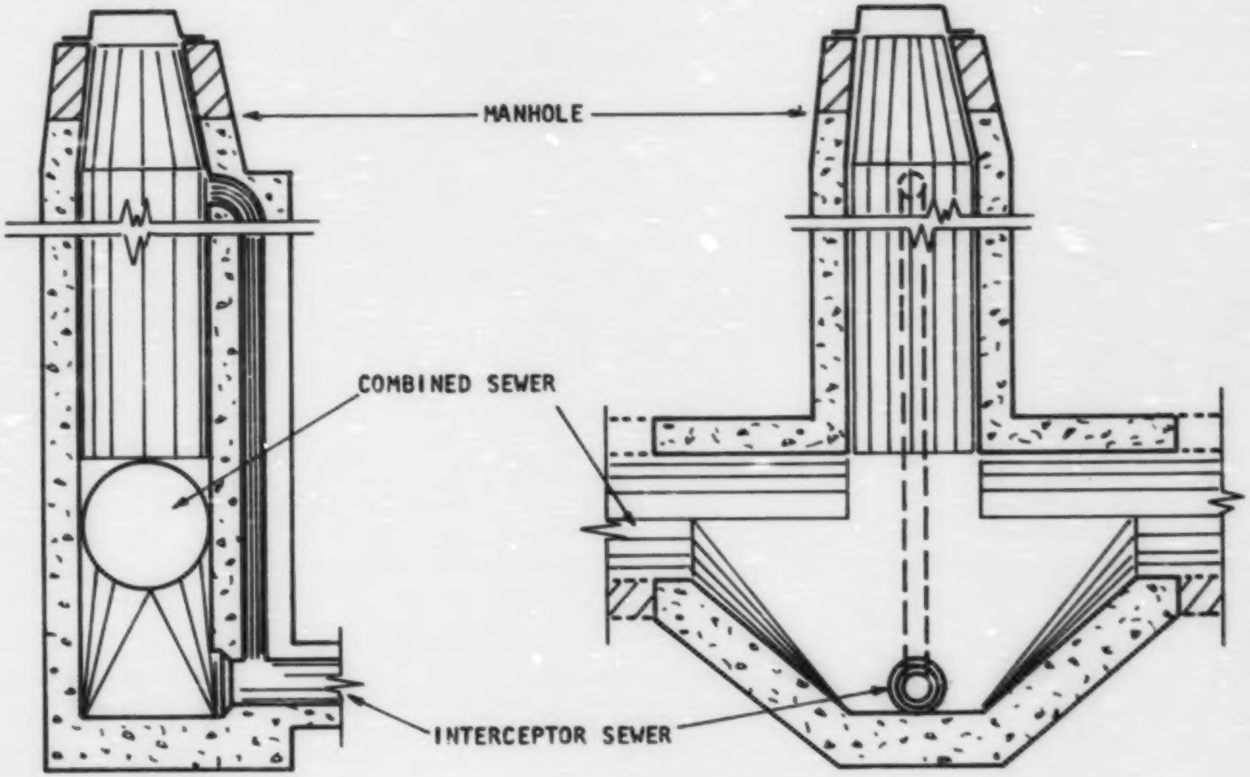


Figure 5. Typical interceptor device

Table 2. CHARACTERISTICS OF COMBINED OVERFLOW - HAWLEY ROAD SITE (FALL 1967 - SPRING 1968)

Date of overflow	Total solids, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	Total COD, mg/l	Dissolved COD,[a] mg/l	BOD (5), mg/l	Coliform, #/ml	Remarks
09/27/67	388	65	---	91	---	---	440	Extended rain
11/02/67	---	---	---	65	---	---	5000	Extended rain--4 days
11/10/67	651	418	---	520	110	---	---	First flushes
11/16/67	664	---	---	210	---	---	---	
11/25/67	649	138	---	159	---	59	4260	First flushes--L. rain
12/07/67	---	232	113	298	50	---	2151	End of overflow
12/21/67	---	242	---	150	30	17	1860	
01/29/68	---	2158	---	1410	60	---	5730	
04/03/68	---	808	---	389	95	---	1388	First flushes
04/03/68	---	194	---	188	48	---	421	Extended overflow
04/17/68	---	228	---	178	---	47	1280	
04/20/68	---	70	---	52	---	13	1850	
04/23/68	---	137	---	134	---	26	6000	
04/28/68	---	461	---	476	---	111	32000	First flushes
04/28/68	---	248	---	311	---	65	26000	Extended overflow
05/20/68	---	194	---	251	---	54	25600	

---

a. See Appendix C Analytical Procedures.

Table 3. SUMMARY OF PRELIMINARY SCREENING DATA

Date of overflow	Screen size mesh	Screen opening, microns	COD Data Raw, mg/l	COD Data Dissolved, mg/l	COD Data After screening, mg/l	COD Data Removal, %	Suspended Solids Raw, mg/l	Suspended Solids After screening, mg/l	Suspended Solids Removal, %
11/10/67	50	297	520	110	407	22	418	270	35
11/16/70	50	297	210	---	182	13	---	---	--
12/07/67	50	297	298	50	247	17	232	---	--
12/21/67	50	297	150	30	121	19	242	195	19
01/29/68	50	297	1410	60	922	35	2158	1526	29
04/03/68	50	297	889	95	559	37	808	707	13
04/03/68	50	297	188	---	121	36	194	183	6
04/17/68	50	297	178	---	134	25	228	207	9
04/20/68	50	297	52	---	51	2	70	67	4
04/23/68	50	297	134	---	99	26	137	122	11
04/28/68	50	297	476	---	331	30	461	331	28
04/28/68	50	297	311	---	199	36	248	177	29
05/20/68	50	297	251	---	188	25	194	153	21
01/29/68	100	145	1410	60	899	36	2158	1504	30
12/21/67	120	122	150	30	66	56	242	68	55[a]
11/10/67	170	87	520	110	340	35	418	210	50
12/07/67	200	74	298	50	233	22	180	150	17
12/21/67	200	74	150	30	117	22	242	178	26
01/29/68	200	74	1410	60	---	--	2158	1368	37
12/07/67	400	37	298	50	200	33	180	100	44
01/29/68	400	37	1410	60	---	--	2158	900	58

a. Flocculated with 1 mg/l Reten A-1 (Hercules, Inc.)

A summary of the preliminary screening data is presented in Table 3. Various mesh sizes from 50 to 400 (297-37 µ openings) were investigated. The majority of the tests were run on a 50 mesh-297 µ opening screen. The laboratory test consisted of pouring the sample through the screen into a beaker. The sample was poured gently to avoid breakup of any particles, and in all tests a mat of solids was not allowed to form on the screen. This eliminated the filtering action which could have resulted if a layer of solids was allowed to form on the screen. It was anticipated that in actual field operation the screens would operate partially blinded and hence the removal rates would probably be higher in the field when compared in the laboratory analysis shown in Table 3. All screen mesh sizes mentioned in this report are Tyler series mesh. Relationship of opening size to mesh size is presented in Figure 6.

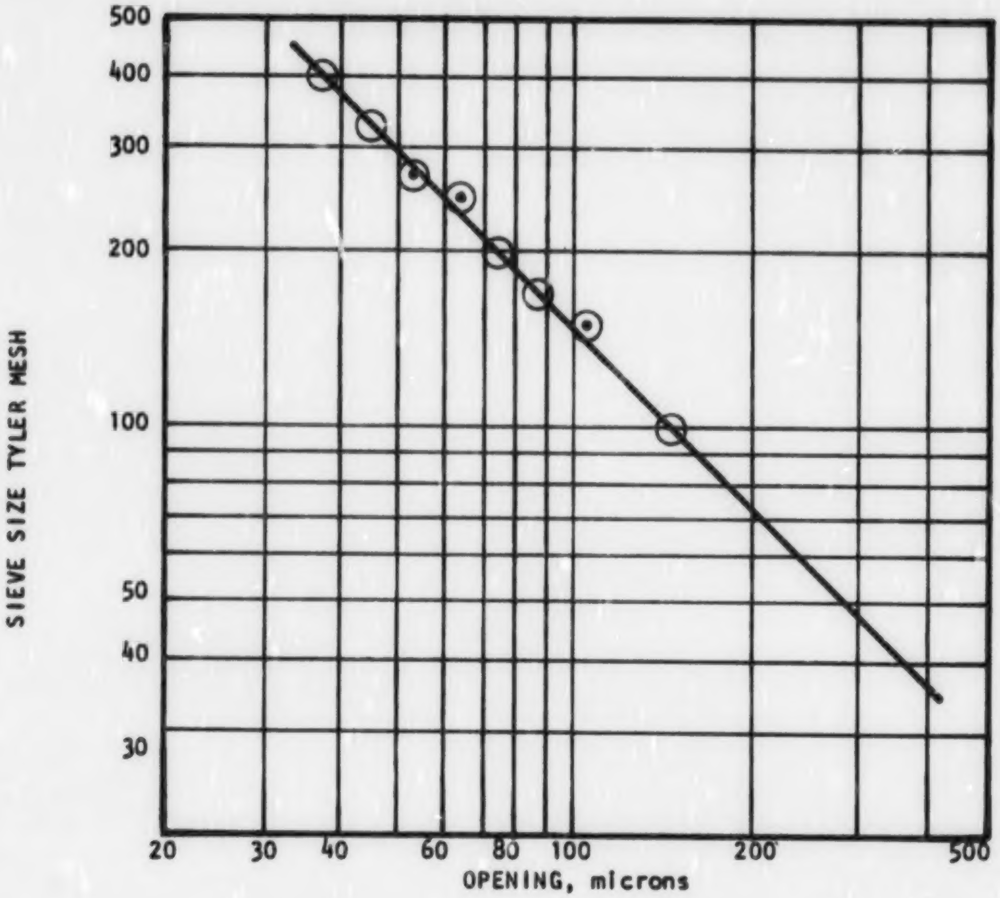


Figure 6. Comparison Tyler mesh to size of opening

Based on the data of Table 3, average removal of suspended solids was 18.6% for a 50 mesh screen, 32% for 100 to 200 mesh screen, and 51% for a 400 mesh screen. An exception to these figures may be seen in the data from 12/21/67 in Table 3. For this test a 120 mesh screen was utilized and the raw waste was flocculated with 1 mg/l of Reten A-1 polyelectrolyte. Removals of COD and suspended solids from this test were 56% and 55% respectively. These removals were significantly higher than those obtained on the same waste (no polymer) using a 200 mesh screen, i.e., COD removal and 26% suspended solids removal (Table 3). These results indicate that flocculation prior to screening can improve the efficiency of the screens. More detailed data, however, is needed to verify these results.

Tables 4 and 5 present the results of the laboratory flotation testing. Table 4 indicates those flotation tests which were run on raw overflow and Table 5 those tests run on screened overflow. The results shown in Table 4 indicated extremely high removals of COD and suspended solids may be obtained using flotation alone in conjunction with polyelectrolyte addition. Bench scale flotation testing was performed using a standard procedure which is detailed in Appendix D. Removals of 73 to 95% COD and 88 to 97% suspended solids were obtained. In Table 5 data on screening/flotation are presented. All the experiments except 5/20/68 were performed without the addition of flocculating chemicals. Based on the data presented in Table 5, suspended solids removals of 41% to 72%, BOD removals of 40% to 62% and COD removals of 42% to 72% were predicted at the 90% confidence level. By comparing the two experiments on the overflow of 5/20/68, the effect of chemical flocculant addition may be seen. Addition of 10 mg/l C-31, a cationic polyelectrolyte, caused an increase in suspended solids removal from 61 to 81%, while the BOD and COD removals increased from 56 and 28% to 63 and 46% respectively.

A summary of preliminary disinfection data collected during the preliminary sampling period is presented in Table 6. Data from ozone and chlorine disinfection are shown. In general, ozone disinfection was not as reliable as chlorine. Ozone demand for these waters was quite high, and since ozone is extremely reactive, a residual ozone concentration could not be obtained except at extremely high dosages (approximately 60 mg/l or greater). Inability to obtain small residual ozone concentrations for a short period of time resulted in the relatively poor E. Coli removals.

Chlorine disinfection on the other hand provided improved disinfection at a dosage of 10 mg/l. Since chlorine is less reactive compared to ozone, some chlorine residual could generally be attained. Disinfection efficiency was better than ozone, but in some tests (April 28, 1968) with high coliform densities, the effluent had significant coliform indicating incomplete disinfection. It appears from this data, as the coliform density increases, higher chlorine dosages will be required.

Table 4. SUMMARY OF PRELIMINARY FLOTATION DATA

Date of overflow	Pressurized flow, %	Deten time, min.	Chemical		COD Data			Suspended solids		
			Type	Dosage, mg/l	Raw, mg/l	Effluent, mg/l	Removal, %	Raw, mg/l	Effluent mg/l	Removal, %
12/21/67	15	3	Reten A-1[a]	1	150	37	75	242	17	93
12/21/67	8	3	Reten A-1[a]	1	150	40	73	242	28	88
1/29/68	15	5	C-31[b]	10	1410	98	93	2524	75	97

a. Anionic polyelectrolyte-Hercules, Inc.
b. Cationic polyelectrolyte-Dow Chemical

Table 5. PRELIMINARY SCREENING/FLOTATION DATA

	4/3/68	4/3/68	4/17/68	4/20/68	4/23/68	4/28/68	4/28/68	5/20/68	5/20/68[a]
Suspended solids									
Raw, mg/l	808	194	228	70	137	461	248	194	194
After screen, mg/l	707	183	207	67	122	331	---	153	153
Screen & flotation, mg/l	279	114	73	55	65	65	---	68	36
Overall removal,%	65	41	68	21	53	86	---	65	81
COD									
Raw, mg/l	889	188	178	52	134	476	311	251	251
After screen, mg/l	559	121	134	51	99	331	199	188	188
Screen & flotation, mg/l	---	---	69	44	64	119	93	114	92
Overall removal, %	---	---	61	15	52	75	70	56	63
BOD									
Raw, mg/l	181	36	47	13	26	111	65	54	54
After screen, mg/l	148	33	33	10	20	92	58	49	49
Screen & flotation, mg/l	85	12	21	10	12	36	27	39	29
Overall removal, %	53	67	55	23	54	68	58	28	46

a. 10 mg/l C-31 added to flotation test - all other runs without chemicals pressurized flow - 20%; pressure 50 psig; detention time - 5 minutes

Table 6. PRELIMINARY DISINFECTION DATA

Date	Type[a]	E. Coli. per ml	Ozone dosage, mg/l.	E. Coli. in effluent per ml	Chlorine dosage, mg/l	E. Coli. in effluent per ml
3 April 1968	FF	1,388	80	21	--	--
3 April 1968	EO	421	59	4	--	--
17 April 1968	EO	1,280	40	74	10	0.5
20 April 1968	EO	1,850	~30	17	10	1
23 April 1968	EO	6,000	<10	3,200	10	2
28 April 1968	FF	32,000	<10	9,500	10	20
28 April 1968	EO	26,000	<10	13,700	10	8

a. FF - First flush
EO - Extended overflow

CONCLUSIONS -- PRELIMINARY INVESTIGATIONS

The following conclusions can be made based on the data taken during the preliminary investigations.

1. Combined Sewer overflow from the Hawley Road sewer contains primarily particulate pollution.
2. Chemical oxidation is not technically feasible for combined overflows.
3. Screening/dissolved-air flotation is a relatively effective method for treating combined overflow.
4. Addition of chemical flocculents greatly increases the removal efficiency of dissolved-air flotation.
5. Disinfection with chlorine was found to be more reliable than with ozone.

SECTION VI

DESIGN AND CONSTRUCTION OF THE 5 MGD SCREENING/FLOTATION DEMONSTRATION FACILITY

The results of the preliminary sampling and laboratory analysis were utilized in the design of a 5 MGD demonstration treatment facility incorporating screening and dissolved-air flotation. This section of the report describes the design criteria utilized, and the features of the demonstration system. A flow sheet for the system is shown in Figure 7 and a photograph of the overall system is shown in Figure 8.

DESIGN OF SCREEN

The design of the demonstration unit involved three basic areas, i.e., screen design, flotation tank design and integration of all system components. Based on removal efficiencies obtained in the preliminary sampling phase, a screen mesh of 50 (297μ openings) was selected. This mesh gave fairly good removal of pollutants (20-30%) and allowed high flow rates (50 gpm/sq ft) at reasonable headlosses. The screen is an open ended drum into which the raw waste flows after passing a 1/2" bar rack. The purpose of the bar rack is to remove large objects which may clog the screened solids removal system or damage the screen material, which is 306 stainless steel. The water passes through the screen media and into a screened water chamber directly below the drum. The drum rotates and carries the removed solids to the spray water cleaning system where they are flushed from the screen. Those solids which will not adhere to the screen media are picked up by 4 angle iron sections which act similar to a roto-dip feeder and are thus removed from the flow. Screened water is used for backflushing the screen. The drum rotation and spray water cleaning are controlled by liquid level switches located in the screen chamber. The switches are set to actuate at a headloss of 6" of water through the screen. The solids which are flushed from the screen along with the spray water are collected in a hopper inside the drum. This hopper is connected to a drain pipe which forms the main axis of the drum. The slurry is then routed to waste. Detailed photographs of the screening system are shown in Figures 9 and 10. These photographs show the screen, internal hopper, float switches, and drive system. The basic screen is fabricated from mild carbon steel. The screen backing material (Figure 9) is a perforated metal plate which has proven to be adequate support for the screen. Hole size for the backing material is 3/4" x 3/4" on 7/8" centers. This provides 73% open area and only a minimum of flow restriction. Rotation speed is controlled by a variable speed drive, which is positioned manually. Rotation speed range is 0.5 - 5 rpm. The screened water is sealed from the raw waste by compressing a tube between

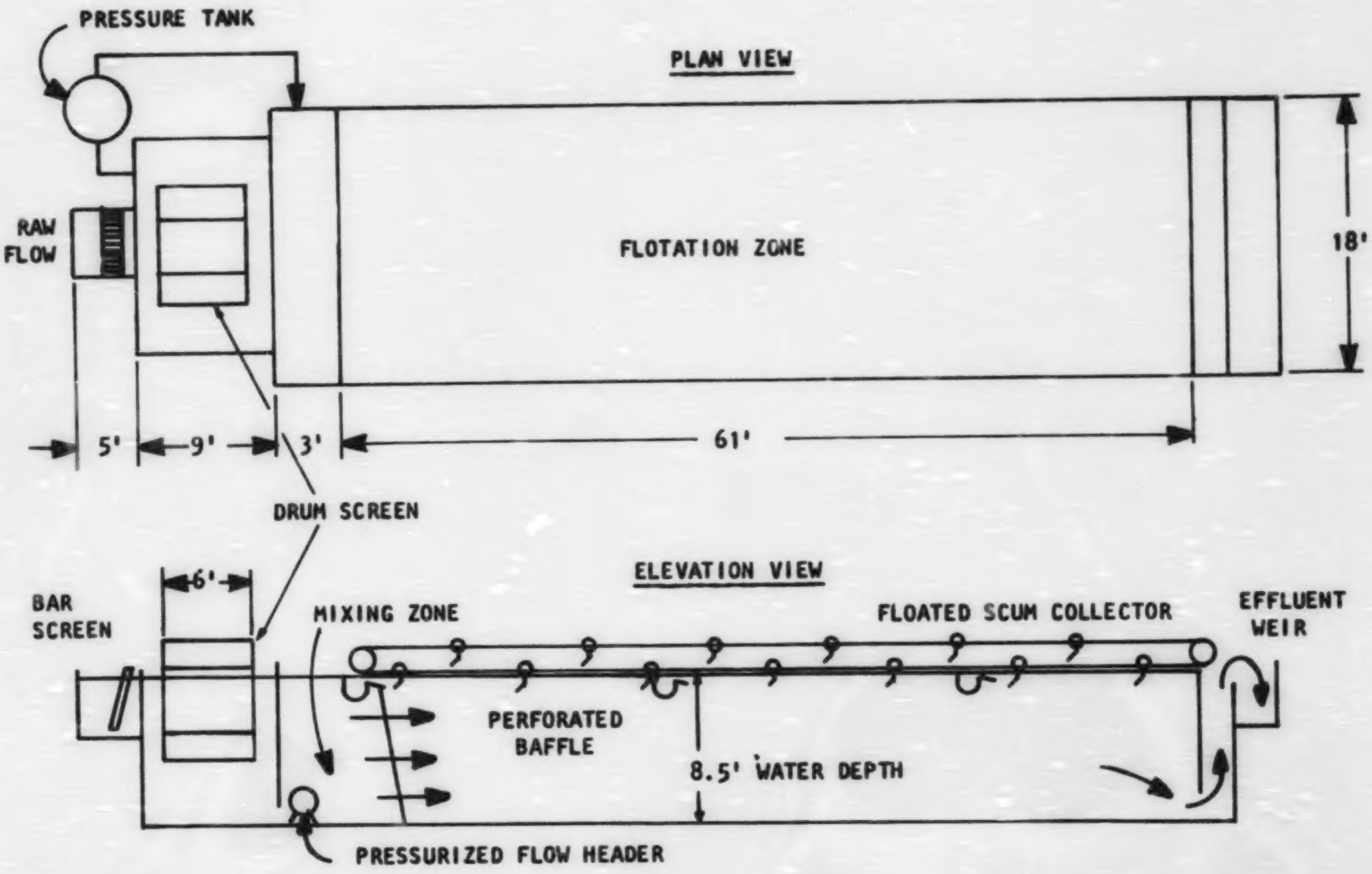


Figure 7. Details of demonstration system

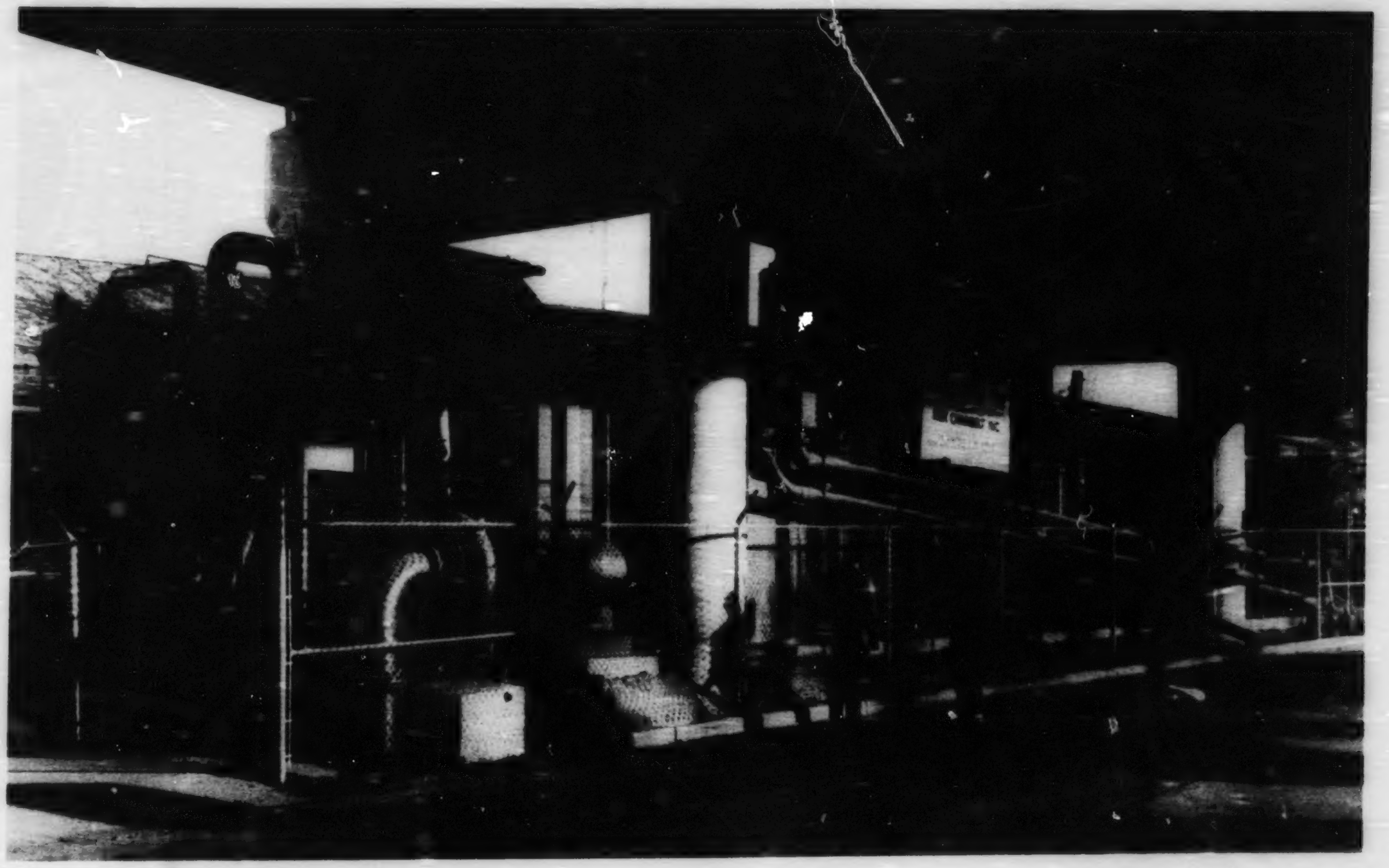
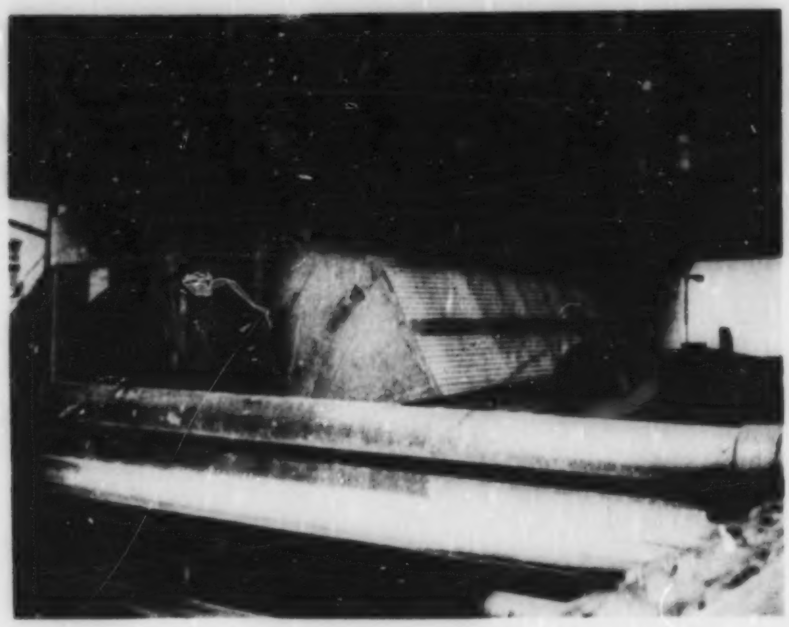


Figure 8. Demonstration system



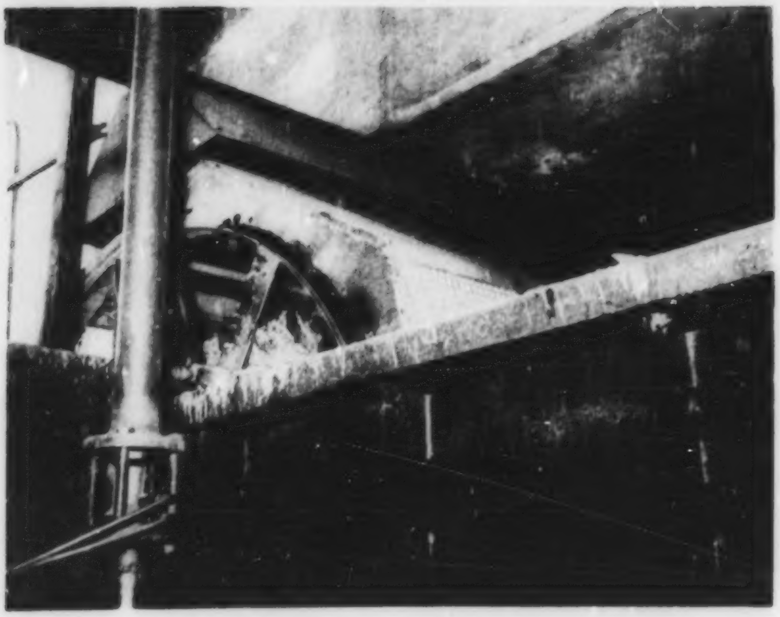


Figure 9. Screening system

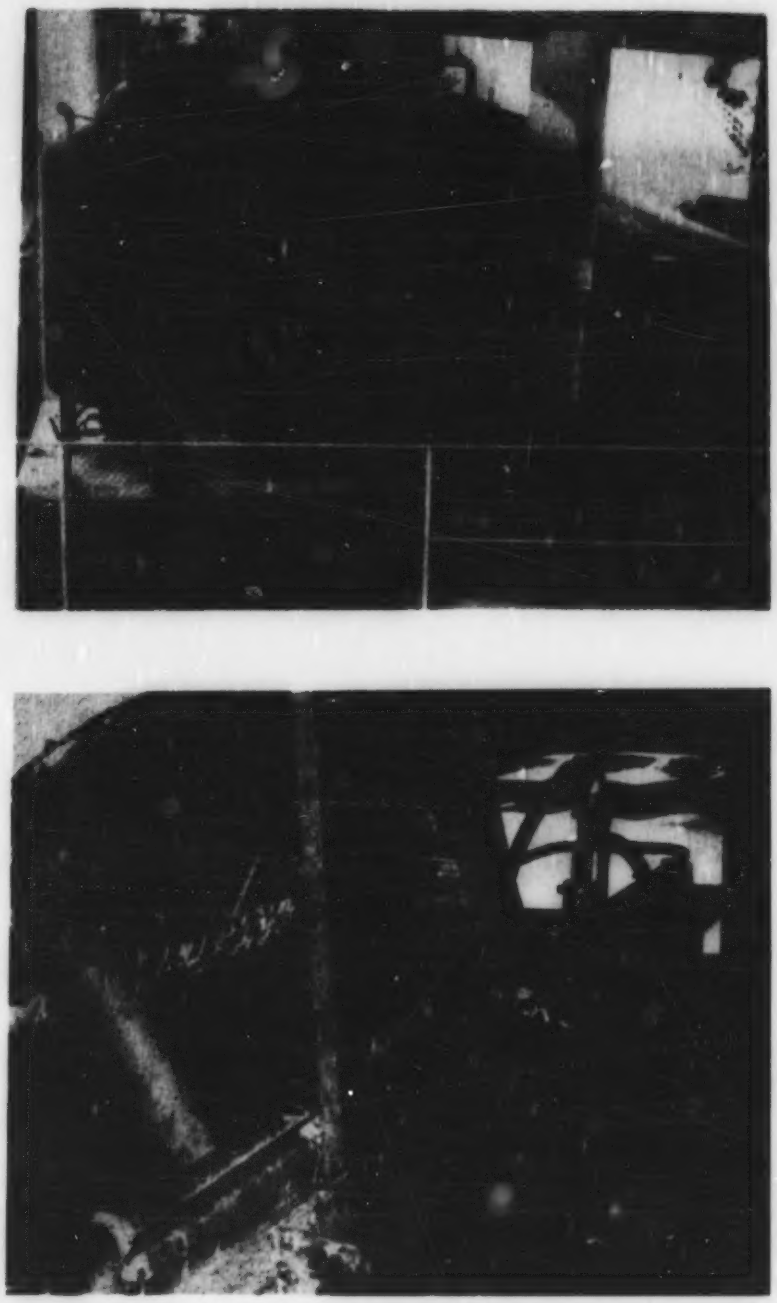


Figure 10. Screening system

the end of the drum and a stationary ring. The sealing arrangement allows operation at a maximum headloss of about 12". Any excess headloss will allow some unscreened water to enter the screened water chamber and a possible raw waste overflow from the bar screen chamber. During some runs with extremely heavy solids loads, the headloss capacity of the screen has been exceeded. These instances will be discussed in a later section of this report.

The drum screen is an 8 sided drum with an effective diameter of 7½ feet. The length of the drum is 6 feet. The 8 panels have dimensions of 3' wide by 6' long. Total screen area is 144 sq ft. The wetted screen area was a minimum of 72 sq ft and a maximum of 90 sq ft depending upon the head loss across the screen.

FLOTATION SYSTEM DESIGN

The dissolved air flotation basin design was based on the criteria utilized by the American Petroleum Institute (API)(64). The major design parameters are overflow rate, detention time, horizontal velocity and depth to width ratio. The design procedures were modified slightly to allow the high flexibility required in a project of this nature.

The basic principle of dissolved air flotation (DAF) is to produce extremely small air bubbles (<100μ) which can be attached to the particulate matter in a wastewater and cause flotation and removal of the particulate matter. To provide these fine air bubbles a liquid stream is mixed with air under pressure. The pressure is then released through a weir type diaphragm valve to form the bubbles. The bubble laden stream is then mixed with the remaining wastewater to be clarified in a contained mixing zone within the DAF tank. This mixing zone has a detention time of approximately 60 seconds. The bubbles attach to the solids in this mixing zone. The bubble formation system is termed the pressurized flow system. Generally, the source of pressurized flow is the process effluent or another relatively solids free stream. In this project the screened water was used as the source of pressurized flow. The advantages to this approach eliminate an increase in hydraulic loading on the DAF tank and provides a simplified plumbing system. Because of the possible presence of a significant amount of solids in the pressurized flow stream, a pressure tank without packing material was utilized. This avoided the potential clogging problems associated with a pressure tank packed with some form of tower packing to increase the air water interface. The type of pressurization utilized in this project has been termed sidestream-pressurization.

The following discussion will delineate the process steps occurring in the flotation tank. Screened water is pumped into the pressure tank. Air is mixed with the water at the inlet to the pressure tank. Water level in the tank is controlled by a liquid level float switch. A slight excess of air is always added. If the water level becomes too low the air stream is vented to atmosphere to allow the water level to rise. Hence, the water level in the pressure tank is positively controlled. There is a deflector baffle in the tank which spreads the incoming water and promotes a large air water interface for good air solution. The pressure in the tank is controlled by an air operated weir valve; this valve provides the proper back pressure as well as the required shearing action to form the small bubbles. This valve is controlled by a pneumatic controller. Once the pressure has been released and the bubbles formed, the bubble laden stream is mixed with the remainder of the screened water flow. A 60 second mixing chamber is provided in the tank prior to entering the flotation zone. This allows time for bubble/solid attachment. When flocculating chemicals are utilized they may be added either to the raw flow or to the pressurized flow after the pressure has been reduced. Generally polyelectrolyte type flocculants, which require little or no flocculation period are added in the pressurized flow stream. Once the pressurized stream and remaining raw waste have been mixed, they enter the flotation zone of the tank where separation occurs. A skimming system skims the floated scum into three separate scum troughs, which convey the scum to ultimate disposal. Generally the solids concentration of the scum is 1-2% solids on a dry weight basis. This concentration flows easily by gravity and does not require screw conveying. Figures 11 and 12 show various details of the flotation system.

The design of the DAF system was such that a wide range of selected variables could be evaluated in order to be able to recommend design procedures specific to combined sewer overflow. The following range of variables is possible with the demonstration system.

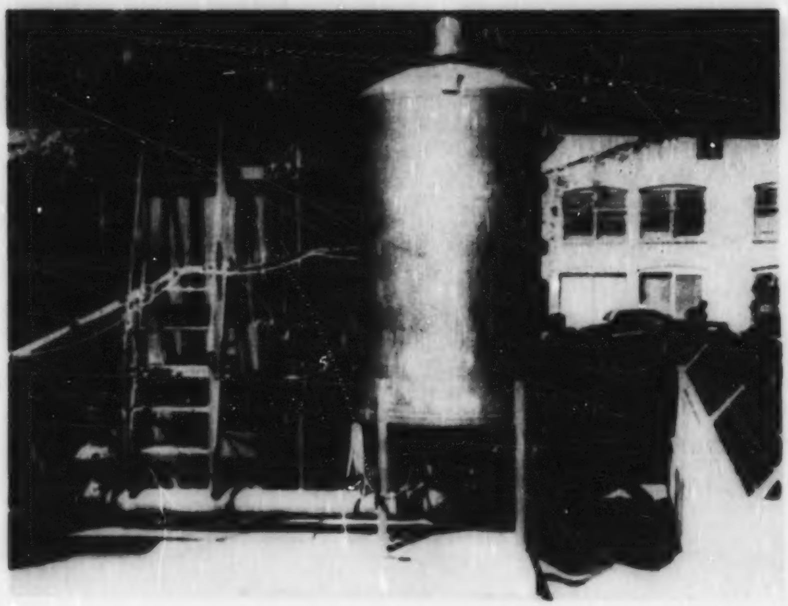
Flow rate	1500 - 4400 gpm
Surface loading	2 - 10 gpm/sq ft
Horizontal velocity	1.30 - 3.75 ft/min
Pressurized flow rate	300 - 1100 gpm
Operating pressure	40 - 70 psig
Detention time	7 - 44 minutes

In addition to the above flexibility, the flotation tank can be divided down the center. This in effect forms two separate flotation tanks. The lengths of these tanks can be controlled by appropriate baffles. This then allows the evaluation of two separate overflow rates on the same storm, thus allowing direct comparison of the overflow rate variable and elimination of all other possible interacting variables. The tank was divided as described above at the start of the 1970 storm period (April, 1970). The final as-built dimensions of the flotation tank were 18 feet wide, 8½ feet water depth, and a 65' long flotation zone.

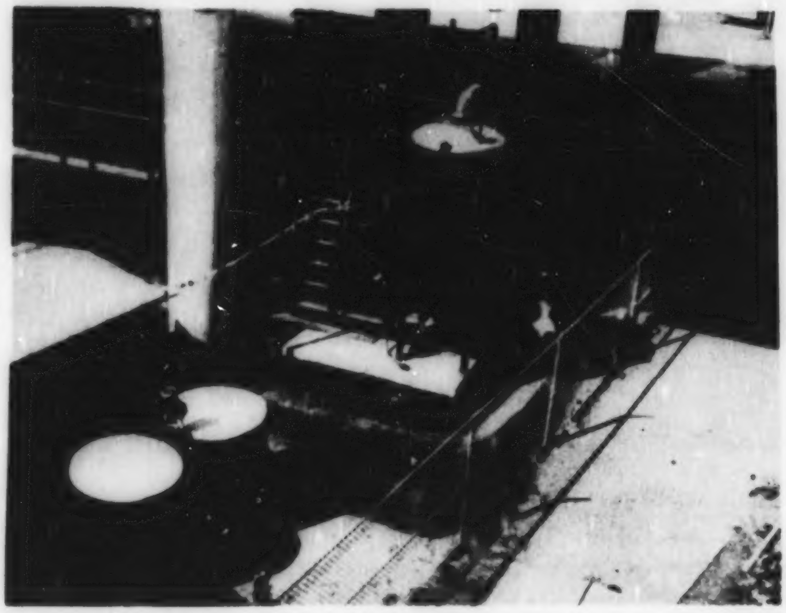
DESIGN OF SUPPORTING SYSTEMS

The appurtenant equipment and tasks necessary to provide a functional demonstrating system included site preparation, construction of a manhole and pumping sump, selection of the necessary flow metering equipment, and design of suitable electrical and pneumatic control systems.

As may be seen in Figure 8, the system was located under an existing highway bridge which provided overhead protection. Site preparation involved laying a concrete slab to provide support for the system tankage. A manhole was

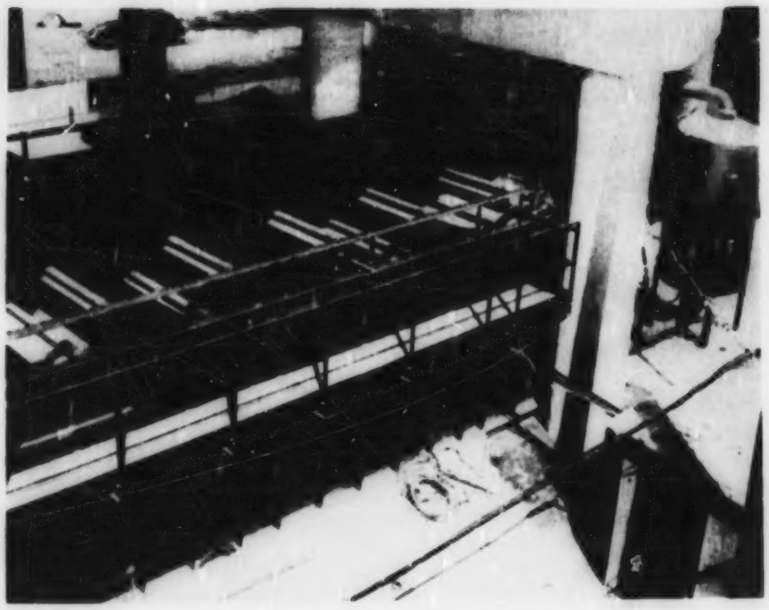


PRESSURE TANK, CONTROL SHACK, AND SCREEN SYSTEM

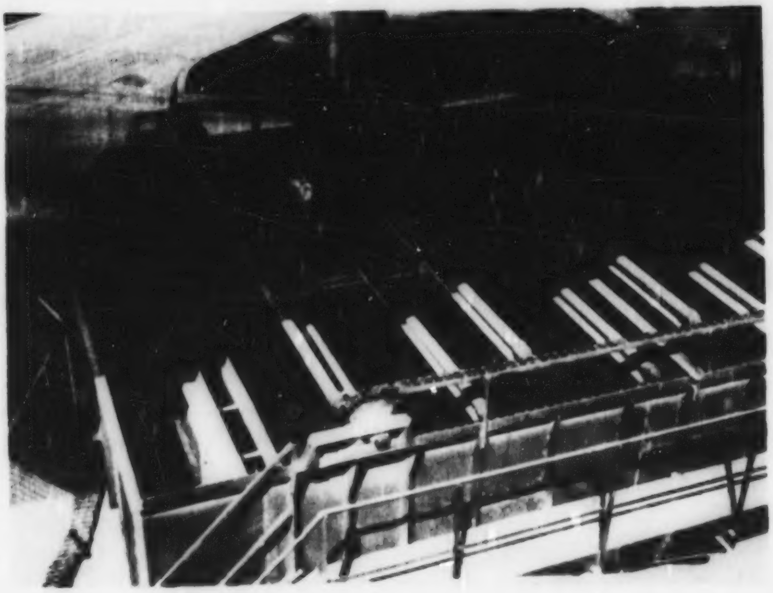


PRESSURE TANK AND PRESSURE REDUCTION VALVE

Figure 11. Flotation system



HEAD END OF FLOTATION TANK



OVERHEAD COLLECTOR AND EFFLUENT STRUCTURE

Figure 12. Flotation tank

constructed as well as a pumping sump, directly in the combined sewer. A dam was also provided in the sewer to allow impoundment of a limited quantity of overflow for subsequent treatment. This dam was designed to tip under the hydraulic pressure of the overflow to prevent surcharging the sewer. A photograph of the outfall is shown in Figure 13.

Flow metering equipment is provided to measure the influent flow rate, the volume of screen backwash water and the volume of floated scum. All other process flows could be obtained by adding or subtracting the proper measured values. The raw flow and screen backwash are measured via venturi meters connected to differential pressure gauges which both record and totalize the flows. The floated scum is measured with an open channel float type meter, which records and totalizes the flow of floated scum.

The electrical control panel provides all necessary controls for 100% automatic operation with manual overrides on all systems. Operational modes will be discussed in a later section of this report. A Merchants Police alarm is connected to the system so that personnel will be alerted when the system goes into operation. The system is always (24 hours per day, 7 days per week) ready to operate, and hence, the maximum possible number of overflows can be monitored. Photographs of the control shack are shown in figure 14.

OPERATION METHODS AND TEST PLAN

Methods and Operational Procedures

The demonstration system previously described was put into operation in May of 1969. Data reported in Section VII represent data taken during the period May, 1969 through November, 1970. During this period 55 overflows were treated with the demonstration system. The system is put into operation automatically when a float switch in the sewer senses an overflow. The pressurized flow system is immediately put into operation and the raw feed pump begins to prime. All runs were started with the tank approximately 80% full of water. The water in the tank was that left from the previous run. The raw feed pump generally primed in about 12-15 minutes. When primed the raw pump is activated, and the flow meters, chemical feeder (if utilized), skimmers and all other auxiliary equipment are put into operation. At the end of the run the system shuts down automatically. All variables are then selected for the next run and the controls positioned. Variables associated with tank operation include pressurized flow rate, operating pressure, scum removal cycle, raw flow rate, and chemical dosage.

SAMPLING PROCEDURES

Sampling began when the raw pump primed. Raw waste and screened water sample collection was started immediately. Effluent sample collection was delayed for 15 minutes to allow purging of the water in the tank from the previous run. This procedure insured collection of representative effluent

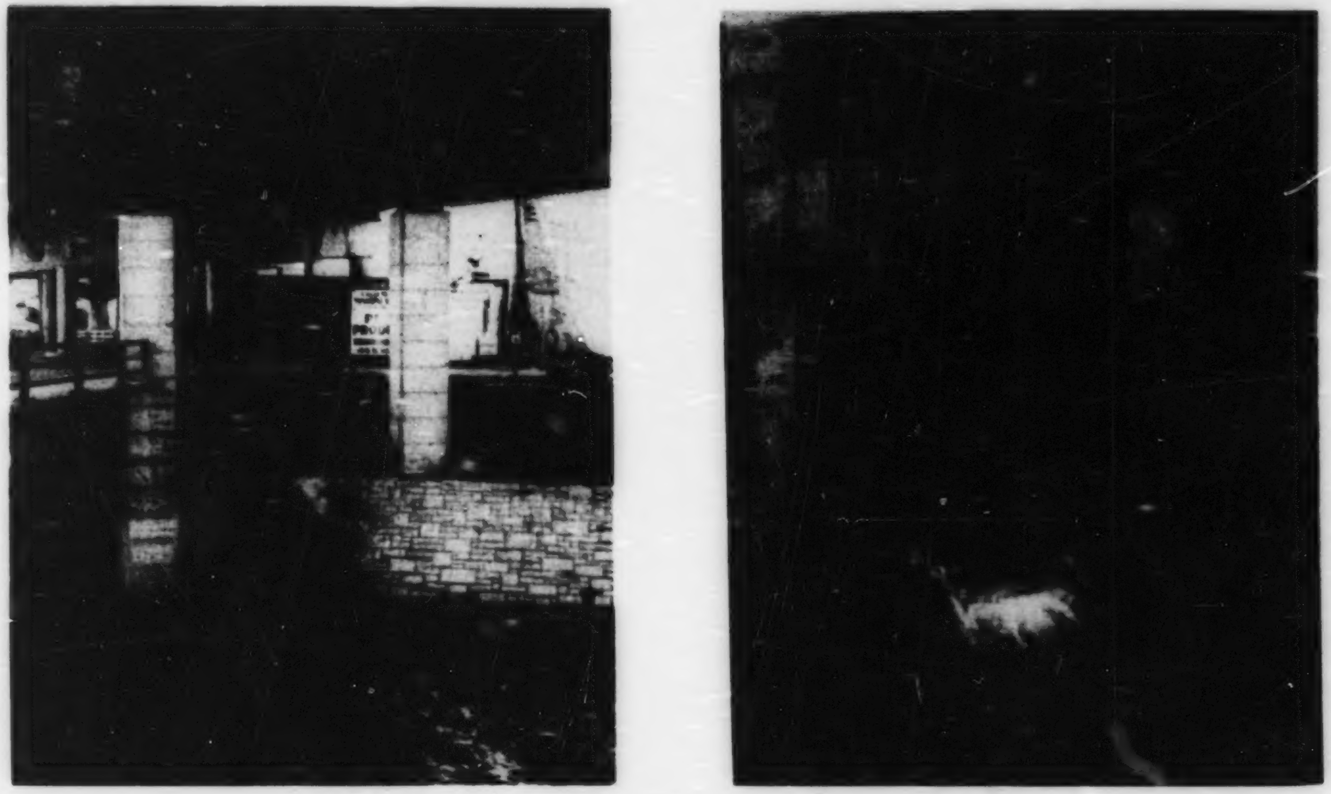


Figure 13. Hawley Road outfall

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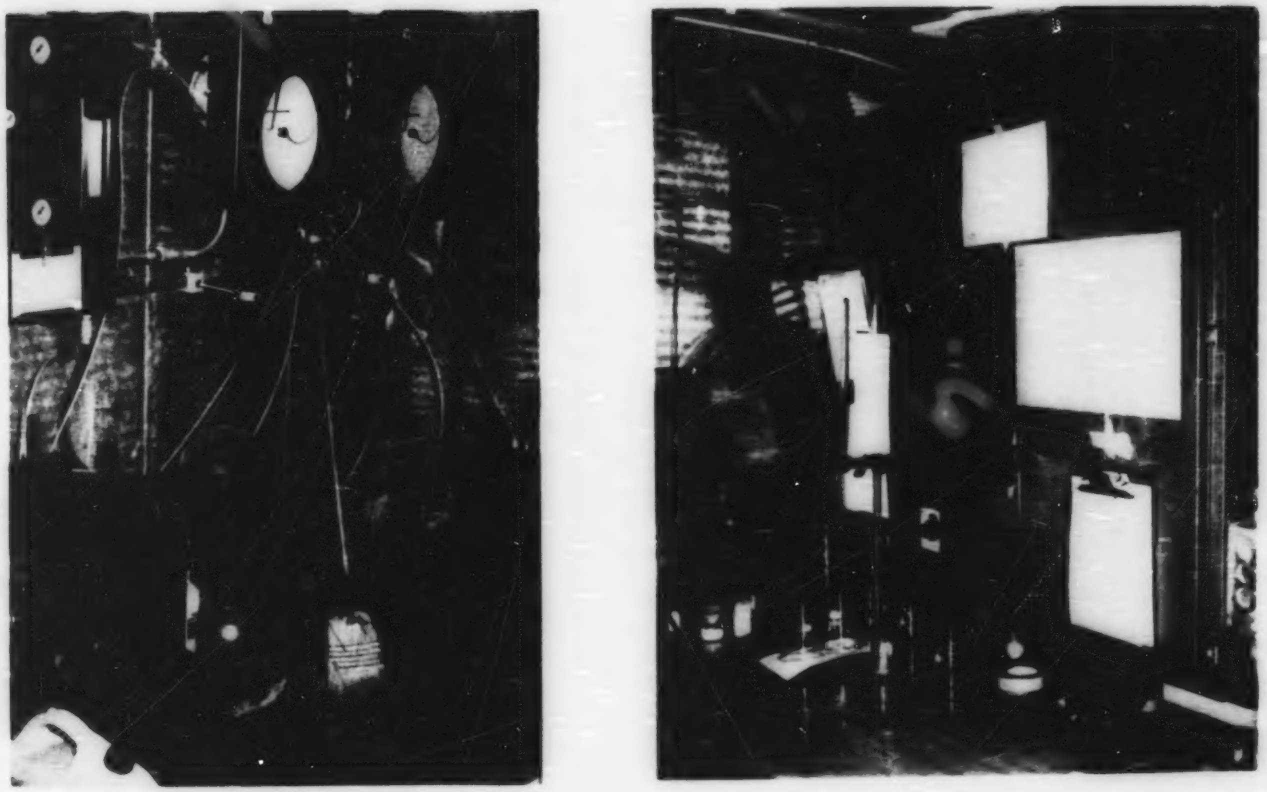

Figure 14. Interior views of the control shack

samples. Screen backwash and floated scum samples were taken during screen backwash and scum removal periods.

Sampling during 1969 runs was manual. Equal volumes of raw waste were taken every ten minutes. Screened water and effluent samples were taken continuously at a rate producing about 2.5 gallons of sample per hour. Screen backwash and floated scum were composited in equal volumes.

An automatic sampling system was put into operation for all 1970 runs. The system consists of two timers connected through the proper valving, to automatically composite the raw waste, screen water and effluent samples. The first timer controls the sample taking frequency (0-30 minutes). The second timer controls the duration of sampling time (0-60 seconds). The sampling valves are air operated weir valves. The automatic system has proven much superior to the manual methods, since the chance for human error has been eliminated and the operator is free to monitor the remainder of the system. In general, samples were composited every 5 minutes with the automatic system. Floated scum and screen backwash sample taking was not automated due to the problems associated with intermittent flows and heavy solids concentrations in these process streams. The samples were refrigerated immediately after the run. Analyses were then started within 0-8 hours. Sample analysis procedures are discussed in Appendix C.

TEST PLAN

Variables associated with the operation of the demonstration system include hydraulic overflow rate (gpm/sq ft of tank area), pressurized flow rate, operating pressure, addition of chemical flocculants, and the floated scum removal cycle. During the first few runs it was determined that values for operating pressure and the removal cycle for floated scum were not critical. A test plan was then initiated with pressurized flow rate, hydraulic overflow rate, and addition of chemical flocculants as the three variables. Eight possible combinations of these variables are shown in Table 7. It was planned to obtain 7 to 8 runs for each variable combination requiring 56 to 64 separate runs. The demonstration system was operated on 55 combined sewer overflows. All variable combinations of Table 7 were fully evaluated except Numbers 3 and 4. These combinations were abandoned based on the results obtained from combinations 1 and 2 which indicated higher overflow rates without chemicals was not feasible.

Table 7. VARIABLE COMBINATIONS UTILIZED FOR FLOTATION TESTING

Combination	Pressurized flow as % of total flow	Overflow rate, gpm/sq ft	Chemical flocculants
1	14-20	2.5	No
2	21-30	2.5	No
3	14-20	3.8	No
4	21-30	3.8	No
5	14-20	2.5	Yes
6	21-30	2.5	Yes
7	14-20	3.8	Yes
8	21-30	3.8	Yes

SECTION VII

SCREENING/FLOTATION OPERATING RESULTS (1969-1970) AND DISCUSSION

CHARACTERIZATION OF RAW WASTE

As was expected, the quality of the combined sewer overflow from the Hawley sewer varied widely. In 12 of the 55 overflows reported herein, extremely high pollutional values were observed. These first flushes persisted for 20 to 70 minutes. A summary of the first flush data may be seen in Table 8. The range of the data presented is at the 95% confidence level. First flush occurence appears to be associated with the length of time between overflows and the intensity of the overflow. The suspended solids concentration for those overflows occurring within 4 days of a previous overflow were calculated to be 151± 29 mg/l while the suspended solids for those overflows occurring at an interval larger than 4 days were found to be 349 ± 80 mg/l. Comparison of the COD data at intervals shorter than 4 days and longer than 4 days produced CODs of 144 ± 21 and 394 ± 72 mg/l respectively. These values are at the 95% confidence level. All the data was tabulated as a function of the interval between overflows. (Table E-10, Appendix E.) This data indicates that essentially all overflows which exhibited the first flush phenomenon occurred at intervals of 4 days or longer between overflows. However, all overflows occurring at an interval of greater than 4 days did not exhibit the first flush phenomenon. Table 9 illustrates this point. All overflows which occurred at intervals of greater than 4 days are presented in Table 9 along with data on rainfall intensity and total rainfall. A total of 23 overflows occurred at intervals of greater than 4 days between overflows. Of these 23 overflows only 12 exhibited the first flush phenomenon. It may be concluded from this data that the length of time between overflows is related to the occurrence of first flushes and there are obviously other variables which strongly influence this phenomenon. These variables could include: the dry weather flow variation, the intensity of rainfall and runoff and the sewer system interceptor capacity. Furthermore the data presented herein may be biased by the 12-15 minutes which was required to prime the raw pump for the treatment system in that extremely short time flushes would not have been detected.

A satisfactory method for measuring the rate of flow in the sewer has not been developed. Development of a method has been complicated due to the presence of the dam, which was placed in the sewer to impound the flow. This dam backs water up past one of the two interceptor devices feeding the Hawley Road sewer. This makes single point gauging impossible. Another complication which arises is the fact that the dam is not stationary. As

Table 8. SUMMARY OF FIRST FLUSH DATA[a]
(95% Confidence Level Range)

Analysis	Concentration, mg/l
COD	581 ± 92
BOD	186 ± 40
Total solids	861 ± 117
Total volatile solids	489 ± 83
Suspended solids	522 ± 150
Volatile suspended solids	308 ± 83
Total nitrogen	17.6 ± 3.1
Ortho phosphate	2.7 ± 1.0
pH	7.0 ± 0.1
Coliform density	142 ± 108 x 10^3 per ml

[a] Data represents 12 overflows

Table 9. SUMMARY OF DATA AT INTERVALS OF GREATER THAN 4 DAYS BETWEEN OVERFLOWS

Run no.	Days between overflows	First flush occurrence	Average rainfall intensity, in/hr	Total rainfall inches
691	18	Yes	0.13	0.42
695	15	Yes	0.32	0.25
6911	8	Yes	0.40	0.50
6912	5	Yes	0.70	1.00
6914	6	Yes	0.35	0.17
6916	12	Yes	0.40	0.10
6919	24	Yes	1.2	0.10
702	26	Yes	0.17	0.3
708	9	Yes	0.84	0.14
7011	14	Yes	0.17	0.25
7013	12	Yes	0.80	0.20
7022	19	Yes	0.10	0.15
6918	11	No	1.6	0.45
6922	17	No	0.3	0.10
6923	6	No	0.5	0.5
6925	11	No	---	0.17
6928	19	No	0.1	0.12
707	7	No	0.4	0.30
7010	11	No	0.11	0.33
7014	6	No	0.18	0.22
7017	8	No	0.36	0.30
7019	18	No	0.15	0.23
7020	15	No	0.24	0.25

the flow increases the dam tips to prevent sewer surcharge. This causes large fluctuations in water level. Down stream of the dam the sewer has a dog leg and extreme turbulence has been observed at the mouth of the sewer. Because of the above discussed difficulties reliable data on the total flow rate in the sewer was not obtained. However, lack of total flow data does not in any way influence the operation of the demonstration system.

Data on rainfall was obtained routinely and runoff rate estimates were made using the rational method. These runoff rates were then plotted against the suspended solids in the overflow. A result of this plot is presented in Figure 15. It appears from Figure 15 that there was no relationship between flow rate in the sewer and the suspended solids in the overflow. This is as expected, since once the sewer system and drainage basin has been thoroughly flushed, the rate of flow should not have a significant effect on overflow quality. However, since actual sewer flow rates were not obtained, a positive conclusion cannot be made.

After the flushes had passed (if they were present), the characteristics of the overflow became remarkably stable, considering the large variations present in the first flushes. The end of the first flushes was determined by visual observation of the raw combined overflow. The screen backwash ran continuously during periods when high suspended solids were present in the raw feed. Thus when the screen backwash pump began cycling the end of the first flushes was indicated. The exact length of the first flushes was not recorded. A summary of all data other than first flushes (termed extended overflows) is presented in Table 10. The data of Table 10 show a relatively small range of values at the 95% confidence level. The data compared well to data from other research on combined sewer overflow (6) (11)(12)(13)(14)(65)(66). The pollutant levels in the extended overflow are about what is expected from a very weak domestic sewage. One major difference is the BOD value of 49 mg/1. This is quite low compared to the COD value of 161 mg/1. Generally, the BOD:COD ratio of domestic sewage is in the range of 0.6 (67). The dissolved solids in combined overflow is also quite low. Total dissolved solids (TDS) based on the data of Table 10, is 212 mg/1. Milwaukee tap water is about 160 mg/1. This represents only about 42 mg/1 TDS increase as compared to ~700 mg/1 usually added when water is used and discarded as domestic sewage (8).

Of particular interest to this project is the amount of organic material present in the dissolved state. Table 11 presents data on this relationship. The amount of dissolved COD ranges from 30 to 38% of the total COD. The dissolved TOC ranges from 26 to 42% of the total TOC. These values are somewhat higher than those obtained in the preliminary sampling phase of 4-25%. The cause of this difference is not known. The dissolved portion of the overflow will not be removed in the screening/flotation system, unless it is chemically precipitated. Hence, lower removal efficiencies will be expected as the dissolved fraction of the waste increases.

A discussion of the results of the operation of the demonstration unit follows. A discussion is divided into three phases: screening operation,

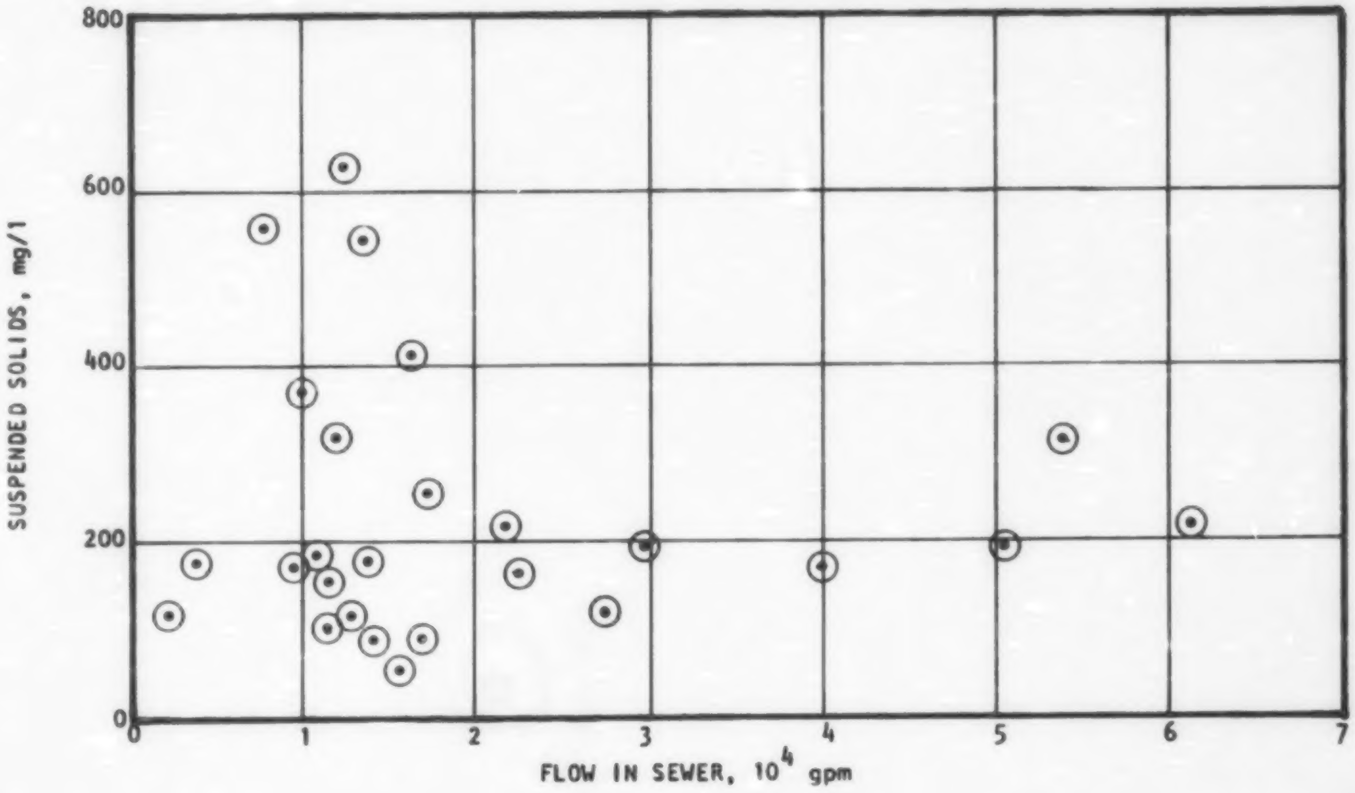

Figure 15. Relationship between flow in sewer and suspended solids

Table 10. SUMMARY OF EXTENDED OVERFLOW DATA[a]
(95% confidence level range)

Analysis	Concentration, mg/l
COD	161 ± 19
BOD	49 ± 10
Total solids	378 ± 46
Total volatile solids	185 ± 23
Suspended solids	166 ± 26
Volatile suspended solids	90 ± 14
Total nitrogen	5.5 ± 0.8
pH	7.2 ± 0.1
Coliform density per ml	$62.5 \pm 27 \times 10^3$

a. Data represents 44 overflows

Table 11. PARTICULATE & DISSOLVED RELATIONSHIPS
(95% confidence level)

Relationship	No. of samples	95% Confidence level
Dissolved COD/Total COD	34	0.34 ± 0.04
Dissolved TOC/Total TOC	13	0.34 ± 0.08
Dissolved TOC/Dissolved COD	14	0.36 ± 0.02
Total TOC/Total COD	17	0.33 ± 0.05

flotation tank operation and disinfection. Because of the wide range of pollutional values obtained in the raw waste, the removals through various processing steps are presented as percentage removals. Absolute effluent water quality data may be seen in Appendix E, Tables E-6 and E-7. Absolute effluent quality can also be estimated by applying the observed percentage removal figures (Table 12 and 13) to the raw overflow water quality presented in Tables 9 and 10.

RESULTS OF THE SCREENING OPERATION

Table 12 presents a summary of the data on removal of pollutants by screening alone. A listing of all data collected is presented in Appendix E, Tables E-4, E-5 and E-6. Generally, the percent removals during the first flush were in the range of 30 to 40%. The confidence band is wide due to the relatively small number of first flush overflow occurrences. During the first flushes a mat of solids sometimes covered the entire screen. This mat acted as a fine filter medium and undoubtedly, increased the removal efficiencies as compared to a clean screen. Unfortunately the headloss increased greatly as the mat formed and in runs 695, 6911, 6912, 6914, 6916 and 702, the headloss capacity of the screen was exceeded for brief periods of time. Examination of these runs indicated that the screen was removing about 200 mg/l of suspended solids which was equivalent to 4.9 pounds of dry solids per minute. Based on screen rotation speed and area, this amounts to a solids loading of approximately 1.2 pounds of dry solids removed per 100 sq ft of screen area. This number represents the critical level of solids loading at which a headloss of 14 inches will be exceeded.

This value of solids loading is specific for a 14 inch headloss across the screen. The loading could possibly be increased by increasing the allowable headloss differential. This could, however, cause a decrease in removal efficiencies by forcing more solids through the screen and/or cause a break up of solids which could affect the efficiency of the flotation process.

The hydraulic flow rate was in the range of 40-45 gpm/sq ft. This rate depending upon solids loading, could probably be increased.

The design of the screening system should be based on both hydraulic flow rate and solids loading rate. Either of these variables could control screen design depending upon waste characteristics.

During the extended overflows and after the first flushes had passed, removal efficiencies dropped to the 20 to 30 percent levels (Table 12). The probable cause of this decrease is that essentially no solids mat formed during extended overflows, and hence, no added filtering action was obtained.

The screen was backwashed with water from the screened water chamber via a pressurizing pump. Spray nozzles with 1/4" diameter orifices were used to effectively distribute the water over the screen media. Washing was

Table 12. POLLUTANT REMOVALS BY SCREENING
(95% confidence level)

Pollutant	Removal during first flushes, %[a]	Removal during extended overflows, %[b]
COD	39 ± 15	26 ± 5
BOD	33 ± 17	27 ± 5
Suspended solids	36 ± 16	27 ± 5
Volatile suspended solids	37 ± 18	34 ± 5

a. Represents 8 overflows (See pages 54-55 for discussion).
b. Represents 46 overflows

performed from outside the screen drum. Some problems were encountered with nozzle plugging due to an inefficient seal on the drum screen. The seal has been improved significantly, but it is still recommended that an in-line small hydraulic cyclone be utilized on future designs to eliminate any operational problems. The volume of screen water required is approximately 100 gallons per minute. Continuous washing of the screen would therefore require about 3% of the raw waste flow. Actual spray wash requirements were in the range of 0.7 to 1.0 percent of the raw flow, since the screen wash did not run continuously during operation. Screen wash quality was in the range of 500 to 3000 mg/l suspended solids (Appendix E - Table E-90). Good media cleaning was always obtained and no permanent media blinding was experienced. In general, operation of the screen was very satisfactory.

OPERATION OF THE FLOTATION SYSTEM

Overall contaminant removals using the screening and flotation systems are presented in Table 13. A listing of all data is presented in Appendix E, Tables E-12 and E-13. During the first flushes, removals of BOD and COD were in the range of 55 to 65 percent,while suspended solids removals were 70 to 75 percent. Removals of nitrogen were significantly lower at about 46 percent. In those first flush runs where flocculating chemicals were added the optimum chemical dosage was generally not obtained, since the pollutant levels were significantly higher compared to extended overflows. This difficulty illustrates the need for some type of control system which would automatically adjust the chemical dosage depending upon the raw feed water quality.

Removals during extended overflows were generally lower than during first flushes. Removals also varied widely depending upon whether flocculating chemicals were utilized. Table 13 presents various pollutant removal efficiencies for three different categories, i.e., without chemical flocculant addition, with polyelectrolyte (Dow C-31) and clay addition, and with polyelectrolyte (Dow C-31) and ferric chloride addition.

Figure 16 presents a probability plot of suspended solids removal for the 1969 data. The slope of the probability line shows a distinct change at about 50% removal. This change in slope indicates some operating variable was affecting the removal rates and caused a change in the normal distribution of the data. This change was chemical flocculant addition. Examination of the data more closely indicated 10 of 14 runs without chemical addition were below 52% suspended solids removal, while 10 of 13 runs with chemical addition were above 52% removal. Removals of volatile suspended solids show trends similar to suspended solids removals.

The effect of optimizing the chemical treatment scheme is clearly illustrated in Table 13. Suspended solids and volatile suspended solids removals increased significantly by varying the chemical addition from polyelectrolyte and clay (1969 data) to polyelectrolyte and ferric chloride

Table 13. POLLUTANT REMOVALS BY SCREENING/FLOTATION
(95% confidence level and overflow rate
~2.5 gpm/sq ft)

Pollutant	During first flushes, %[a]	Removal during extended overflows, %[b] Without chemical flocculants (1969-1970 data)	With chemical flocculants (1969 data)[c]	With chemical flocculants (1970 data)[d]
COD	64 ± 6	41 ± 8	40 ± 14	57 ± 11
BOD	55 ± 8	35 ± 8	46 ± 17	60 ± 11
Suspended solids	72 ± 6	43 ± 7	59 ± 11	71 ± 9
Volatile suspended solids	75 ± 6	48 ± 11	58 ± 10	71 ± 9
Total nitrogen	46 ± 7	29 ± 14	19 ± 11	24 ± 9

a. Represents 12 overflows
b. Represents 38 overflows
c. 2.5 - 3.5 mg/l C31, 6 mg/l clay
d. 3-6 mg/l C31, 20-25 mg/l $FeCl_3$

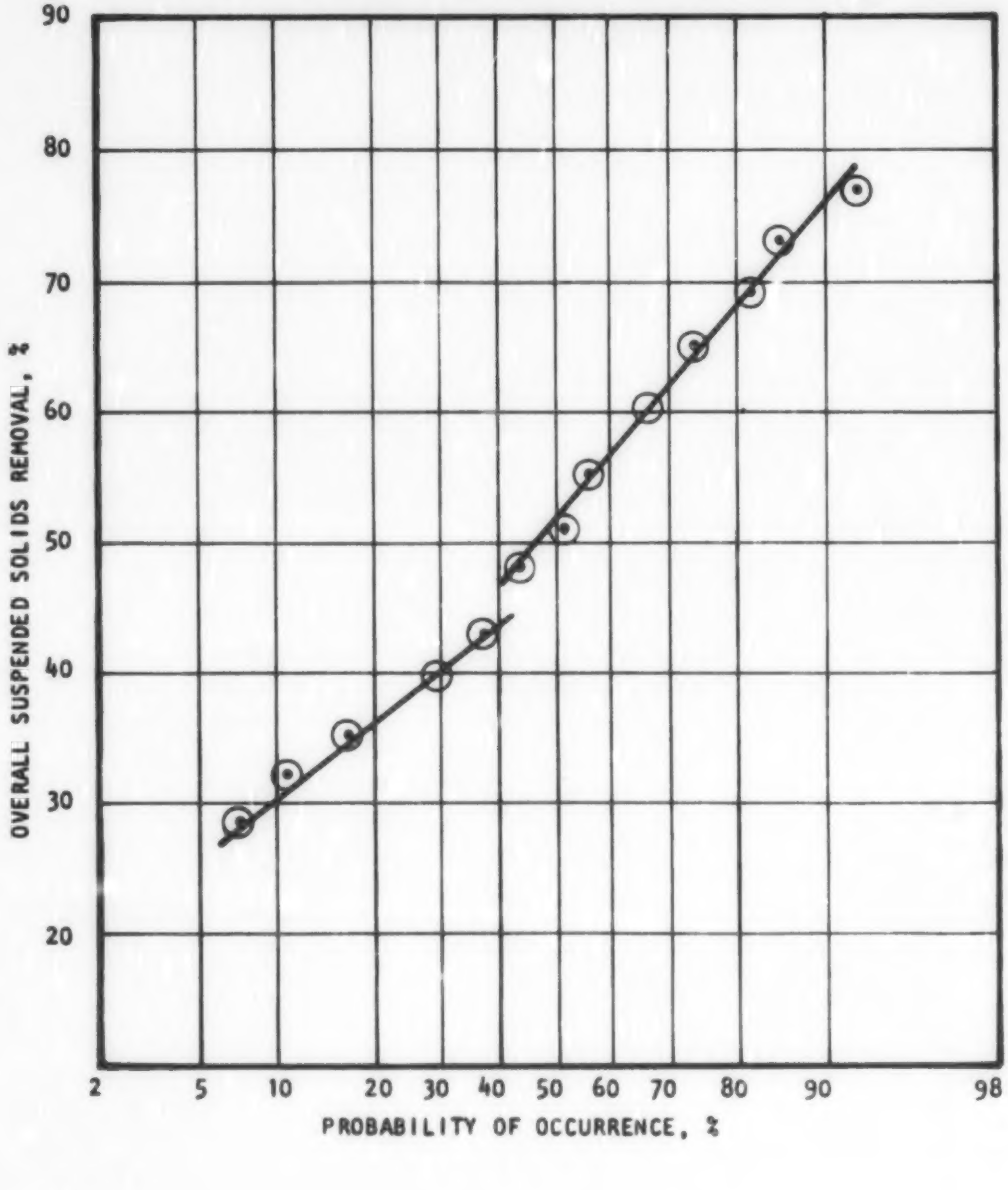

Figure 16. Suspended solids removal-screening/flotation

(1970 data). The chemical dosage required to provide consistent removals was found to be 20 mg/1 ferric chloride and 4 mg/1 polyelectrolyte. The ferric chloride is added to the raw waste water flow prior to screening and the polyelectrolyte is added to the pressurized flow stream prior to mixing with the remainder of the screened waste flow.

The BOD and COD data also indicate increased removals when chemical flocculants were added. An exception to this observation is the COD removal data with and without chemicals for the 1969 overflows (Table 13). It is felt that the small decrease in COD removals was due to an increase in the dissolved organic fraction of the raw combined overflow. During late summer and fall leaves and other decaying organic material can cause a substantial amount of organic material to be converted to the dissolved state. This was very evident in run number 6919 as the appearance of raw waste after filtering was quite yellow. Run numbers 6928, 6929 and 6930 also had a very high dissolved fraction. This increase in dissolved organics resulted in the small decrease noted when chemical flocculants were added, since dissolved organic removals can be accomplished only by precipitation. Apparently, the dissolved organic material was not exerted as BOD (5) possibly due to unacclimated organisms and BOD removals were therefore not affected to the same degree as COD removals.

A summary of removal efficiencies for particulate organic material is presented in Table 14. It may be seen that during the 1969 runs, numbers 6923 through 6929, particulate COD removal ranged from a high of 96% to a low of 34%. It is obvious from the spread of the data that effective coagulation was not always being achieved. During the 1970 runs (700 Series) particulate COD removals were much more consistent reflecting the improved chemical treatment system, i.e., ferric chloride and polyelectrolyte addition. The average particulate COD removal efficiency for the 1970 data was 76±8% at the 95% confidence level. This value compared closely to the suspended solids removals for the 1970 data of 71±9% (Table 13) thus indicating that effective chemical treatment was generally obtained during the 1970 overflows. There are, however, some overflows (7012, 7014, 7015, 7023) where the particulate COD removals were below the 95% confidence range. This further illustrates the need for some type control system for metering the chemical addition.

Removal of dissolved organic compounds can only be obtained by precipitation of the material or absorption on the flocculated particles obtained when polyelectrolyte or other flocculating chemicals were added to the raw waste stream. Removal of dissolved COD for those runs, where data is available, is presented in Table 14. As expected, removal of dissolved COD was erratic and ranged from no removal to a high of 43% removal. Generally, the removals were in the range of 20 to 25%. Other chemical flocculants may give slightly improved removals, but 20-30% removal of dissolved organics is all that can be expected in a screening/flotation system.

It has been determined from laboratory studies that a flocculation period may further improve the removal efficiency of the flotation process.

An important variable in the operation of a dissolved-air flotation system

Table 14. SUMMARY OF PARTICULATE AND DISSOLVED ORGANIC REMOVAL EFFICIENCIES

Run #[a]	Chemical dosage C-31, mg/l	FeCl$_3$, mg/l	Clay, mg/l	Particulate COD removal, %	Dissolved COD removal, %
6923	6.0	0	6	54	+2
6924	0	0	0	34	+14
6925	0	0	6	86	+25
6926	2.7	0	0	83	+22
6927	0	0	0	73	+23
6928	3.0	0	0	57	+23
6929	3.0	0	3	39	+23
704	6.0	0	0	63	+11
705	6.0	0	0	95	0
706	6.0	0	0	95	-2
707	6.0	0	0	74	+10
708	6.0	0	0	85	-3
709	4.2	30	0	88	+20
7011	5.3	17	0	87	+27
7012	3.9	16	0	53	-19
7013	4.6	16	0	80	+30
7014	3.5	21	0	42	+31
7015	4.5	21	0	50	+29
7016	4.5	21	0	93	+4
7018	4.5	21	0	87	+8
7019	4.5	21	0	77	+33
7020	3.8	18	0	81	+40
7021	3.8	18	0	91	+24
7022	0.5[b]	15	0	88	+43
7023	0.5[b]	15	0	48	+21
7024	0.5[b]	25	0	78	-3
7025	4.0	25	0	69	+22

a. Overflow rate ~2.5 gpm/sq ft

b. Herco floc 810 used for these overflows is the volume of pressurized flow required to supply sufficient air bubbles for proper process operation. For a given volume of liquid, the number of bubbles and their size will be a function of the operating pressure. Generally the greater the pressure, the larger the volumes of air dissolved and the smaller the size of the bubbles. There is of course a limit to the benefit to be gained by increasing operating pressure. Pressurized flow volumes generally utilized are in the range of 15-50% of the raw waste flow. Table 14 presents a comparison of pressurized flow ratios utilized. Rates from 13 to 22% of the raw flow were considered low values while rates from 23 to 44% were considered high values. The data is further segregated into those runs with and without chemical flocculant addition. A comparison of means test (68) was performed on the high and low pressurized flow values of Table 15. The procedure for performing this test may be seen in Appendix E. The results of this comparison indicated there was no statistically significant difference between suspended solids removals for low or high pressurized flow whether or not chemical flocculants were utilized.

It appears, considering all data, that a pressurized flow value of 20% of the raw flow will be sufficient for dissolved-air flotation operation on combined sewer overflow. A slight increase in pressurized flow may be required if the improved efficiencies predicted in the laboratory are obtained in the field, since a larger volume of solids will require floating. Air requirements based on a 20% pressurized flow system would be 1.4 SCFM per million gallons per day of raw flow capacity. An operating pressure of 50 psig provides sufficient air solution and a small enough bubble size to be effective without requiring excessive pressure drops at the pressure reduction value.

Another variable which can significantly affect the removal efficiencies of a dissolved air flotation system is the overflow rate, i.e., gpm/ sq ft of tank area. Removal data presented in Table 13 were all at the overflow rate of approximately 2.5 gpm/sq ft.

To allow for a study of higher overflow rates, the flotation tank of the demonstration system was partitioned as shown in Figure 17 for all 1970 runs. All process elements up to the point of entering the flotation zone were identical to the 1969 runs. A longitudinal baffle was placed the entire length of the tank. This had the effect of producing two separate flotation zones. Lateral baffles were then placed at one-half the length of the tank on side one and at two-thirds the length of the tank on side two. Effluent samples were taken just as the water flowed under these baffles to insure collection of a sample representative of the portion of the tank being utilized. The unshaded area of Figure 17 represents the unused portion of the tank. The raw flow as it enters the flotation zone is split into equal volumes. Since the effective length of each side of the tank is different, two overflow rates are thus obtained on the same storm. This completely eliminates the effect of any interacting variables like pressurized flow, chemical addition, and the differences inherent in any two combined overflows, allowing direct determination of the effect of overflow rate.

Table 15. EFFECT OF PRESSURIZED FLOW RATE ON SOLIDS REMOVAL

Low pressurized flow				High pressurized flow			
Run #[a]	Pressurized flow,%	Chemical flocculents utilized	Suspended solids removal,%	Run #	Pressurized flow,%	Chemical flocculents utilized	Suspended solids removal,%
6911	17	No	30	692	24	No	40
6912	21	No	55	693	29	No	65
6914	13	No	80	695	34	No	44
6915	16	No	53	696	29	No	34
6917	16	No	64	697	31	No	28
6924	16	No	48	699	23	No	40
6927	18	No	61	6910	23	No	32
7012	17	No	52	6913	33	No	63
				6917	23	No	64
				6925	29	No	46
Average	16.8	--	55	Average	27.8	--	46
6920	21	Yes	70	6919	28	Yes	65
6921	17	Yes	57	6926	31	Yes	75
6922	16	Yes	66	6929	2[illegible]	Yes	45
6923	20	Yes	52	704	37	Yes	77
6928	19	Yes	49	705	44	Yes	79
6930	19	Yes	40	706	40	Yes	80
707	22	Yes	68	709	28	Yes	82
708	22	Yes	76	7011	24	Yes	69
7015	19	Yes	37	7013	23	Yes	72
7016	20	Yes	85	7014	28	Yes	68
7018	20	Yes	86	7021	23	Yes	72
7019	20	Yes	71	7023	25	Yes	49
7020	19	Yes	85	7024	27	Yes	66
7022	19	Yes	85				
Average	19.5	--	66	Average	29.6	--	69

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a. Overflow rate @ ~2.5 gpm/sq ft

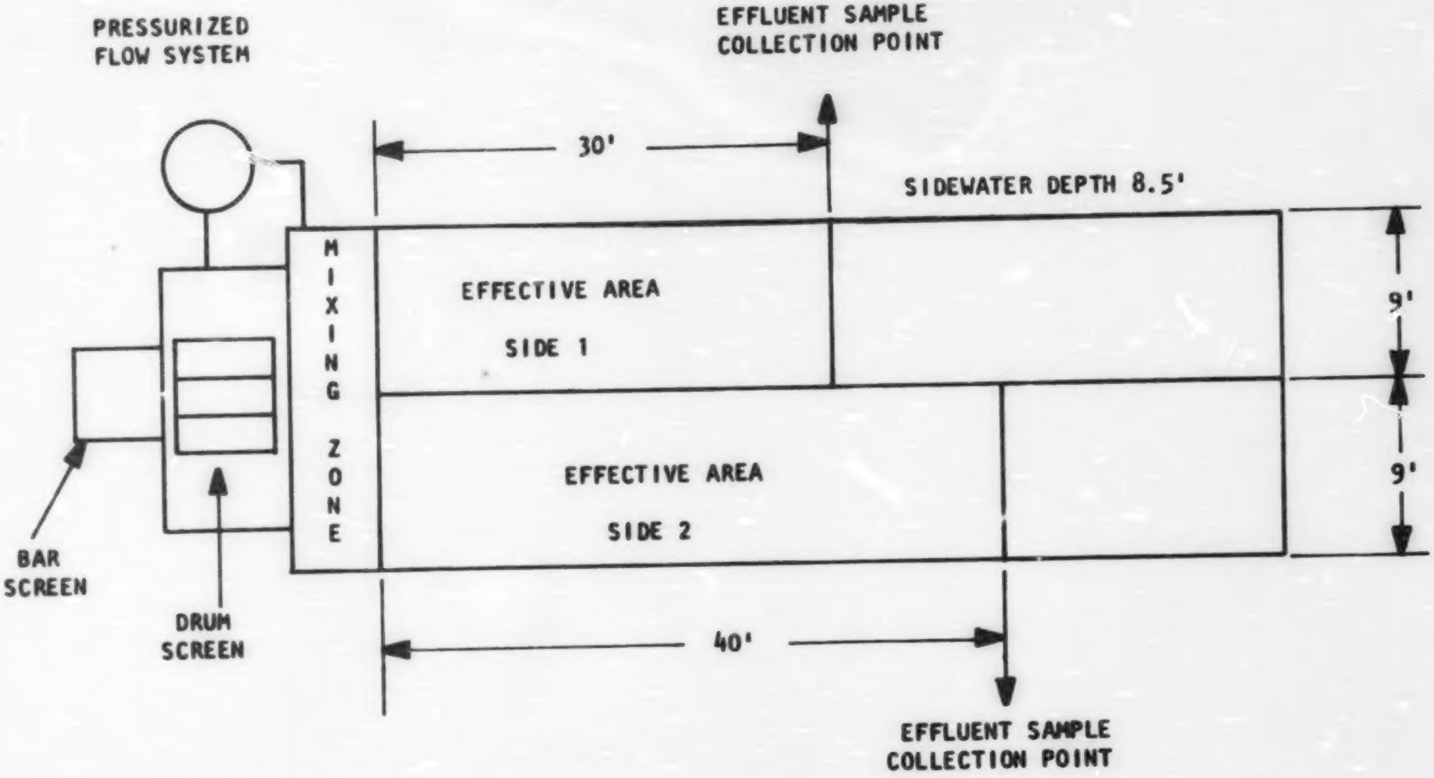

Figure 17. Baffle arrangement for overflow rate tests

Data taken on direct comparison of overflow rates are presented in Table 16. The data indicates removal efficiencies decrease as the overflow rate is increased. Data from each run is presented, as well as average values for low and high overflow rates along with the 95% confidence range. By comparing the mean values, removal efficiency decreased approximately 5-14% as the overflow rate increases from ~2.5 to 3.75 gpm/sq ft. A paired comparison test (Appendix E) was also run on the data of Table 16. The results of this test indicated that there was a difference in the low and high overflow rate data. Confidence levels at which the difference was significant are as follows: COD - 90%, BOD - 95%, suspended solids 99% and volatile suspended solids - 95%. It is anticipated that at higher overflow rates the decrease in removal efficiencies will be even greater.

Of considerable importance in the operation of a screening/flotation system is the volume of residual solids produced during operation. Volumes of floated scum generated during operation of the demonstration unit ranged from 0.75 to 1.41 percent of the raw flow at the 95% confidence level. Scum concentration was generally in the range of 1 to 2% solids on a dry weight basis (Appendix E, Table E-9). The floated scum and screen wash-water from this project are disposed of via an interception sewer which directs them to the sewage treatment plant for ultimate disposal. Since gravity flow is utilized it is desirable to limit the sludge concentration to about 2% as this concentration easily flows by gravity. Higher concentrations can be obtained by skimming the floated scum blanket at less frequent intervals. Sludge concentrations as high as 4% solids have been obtained in this manner. Obviously the higher the concentrations, the smaller the volume of sludge produced for ultimate disposal. For this reason it is felt that in full scale operations sludge volumes will be somewhat less than those obtained during this study. Another factor, which will offset this reduction in scum volume, is the addition of more effective chemical flocculants. As the chemical flocculant addition is optimized, the volume of scum will increase due to the additional chemicals added and the higher efficiency of solids capture.

Ultimate solids disposal will dictate the desired solids concentration in the floated scum and, hence, the volume of scum which requires disposal. If scum is disposed of by way of an interceptor sewer a solids content in the range of 1-2% will be desirable. This should result in an average scum plus screen wash volume of 1.75 percent of the raw flow. If disposal is by tanker truck or solids dewatering at the site, a high solids concentration is desired (4%), and the volume should be less than 1 percent of the raw flow.

During the operation of the demonstration system some settled sludge was noticed. The amounts of settled sludge were, however, extremely small, with one exception. Runs number 691 and 692 were made without using the drum screen. Upon draining the tank after run number 692, about 4-6" of settled material was discovered. This consisted of grit, twigs and other material which could not be floated. Later in the year the tank was again drained after 13 additional runs which were all made with the screen in service. Settled sludge volume amounted to only 2-3 inches at this

Table 16. COMPARISON OF THE EFFECT OF OVERFLOW RATE ON REMOVAL EFFICIENCIES[a]

Run	Low overflow rate ~2.5[b]				High overflow rate ~3.75[c]			
#	COD	BOD	SS	VSS	COD	BOD	SS	VSS
704	35	69	77	90	28	55	33	51
705	72	69	79	79	74	69	79	80
706	76	75	81	73	72	54	66	64
707	52	61	68	72	43	58	50	62
708	67	59	76	77	62	36	66	71
709	66	51	82	76	61	51	76	73
7011	63	60	70	76	60	64	74	79
7012	41	36	52	58	36	31	36	56
7013	56	55	72	80	48	46	66	69
7014	36	--	68	68	29	--	66	68
7015	43	37	52	47	39	40	48	27
7016	74	--	85	84	71	--	83	82
7020	74	77	85	86	68	45	63	69
7021	58	76	72	70	67	80	67	68
7023	37	51	49	49	46	46	35	36
7024	61	52	66	61	51	46	56	70
7025	50	62	59	61	60	64	68	70
Average	56.5	59.3	70.2	70.7	53.8	52.3	60.7	64.4
95% Confidence limits	49-64	52-66	64-76	64-77	46-62	45-60	53-69	57-72

a. Removal in %
b. Actual range 2.43 - 3.1 gpm/sq ft
c. Actual range 3.4 - 4.5

Note: Chemical flocculants added for all runs draining. This clearly demonstrates the value of the screen in removing heavy particulate matter which cannot be floated in the flotation tank. The tank was again drained at the end of the 1969 season and sludge volumes were again only 2-3 inches. It may be concluded that bottom skimming systems are not required when screening precedes flotation. If, however, applications arise where flotation is used alone, it is imperative that some type of bottom skimming be provided or large sludge blankets will form which will eventually scour into the effluent.

Material balances for suspended solids were made for almost all runs. The tabulated data may be seen in Table E-14, Appendix E. The balance of solids in and solids out of the system generally totaled within about 25%. In some cases, however, the error was higher. The probable reasons for the material balance errors are believed to result from scum sampling and collection procedures. At the end of a run, the floated scum blanket which remained on the tank was lost with respect to material balances. Generally this scum was skimmed off after the run when the scum meter was not totalizing. It was also difficult to obtain a representative sample of scum, since scum was scraped intermittently and the solids concentration could vary widely from the beginning to the end of the skimming cycle. Scum samples were taken manually and if other operating problems arose, a scum sample from every skimming cycle may not have been obtained. Because of the sampling procedures it is felt that scum suspended solids concentrations were not representative. Since suspended solids in the scum could account for a significant portion of the solids balances, it is felt that these errors contributed to a large extent in the material balance discrepancies.

OPERATIONAL DIFFICULTIES

Difficulties were also experienced with the raw flow meter totalizer. The units on the totalizer were 30,000 gallons per count and thus could not be read accurately. The totalizer has subsequently been changed and thus this problem eliminated. Another possible source of material balance error is the fluctuating concentration of the raw overflow. Limited data has been collected to indicate that the pollutant concentration can vary significantly during an overflow. This variation could introduce errors in the material balance.

The following discussion will be limited to those problems which were encountered and the method of solution. Some difficulties were encountered with the float switches utilized in the system. These switches are the reed type which are activated by a sliding float. They required frequent cleaning, once per week, as sand would work its way between the float and the shaft and cause the float to become inoperable. Replacement of this type of switch with a conductivity type should solve this problem.

Difficulties were also encountered with the back pressure control valve on the pressurized flow system. This problem resulted from excess moisture in the compressed air. All problems were in the positioner for the valve which accepts a 0-20 psi control pressure and positions the valve accordingly.

The positioner was utilized only because of the design flexibility required in a demonstration system. In the full scale applications when the pressurized flow rates are known, valve positioners will not be required and the problems incurred will be eliminated.

A minimum amount of difficulty was experienced with the chemical metering pump, but this was a result of improper materials selection and the difficulties were easily eliminated. As may be concluded from the above discussion, the operation problems encountered were minimal and this attests to the soundness of the system design.

DISINFECTION OF COMBINED OVERFLOWS

Another important aspect in the treatment of combined sewer overflows is adequate disinfection. The screening/flotation system provides sufficient detention time (12-20 minutes) to obtain the necessary chlorine contact time. The system also is flexible in that various points of chlorine addition are available depending upon process needs. A summary of the disinfection data taken during the project is presented in Table 17. Hypochlorite salts were utilized as a source of chlorine. Dosage was held essentially constant at 10 mg/l. It was noticed, however, that the strength of the chlorine stock solution could decrease rapidly depending upon environmental conditions. Therefore, some of the storms could have had dosages less than 10 mg/l. In general, relatively good disinfection was obtained. A trend seems to exist in Table 17 which indicates that as the coliform density increases the absolute coliform density in the effluent also increases. Nevertheless good disinfection can be obtained in conjunction with the operation of a screening/flotation system.

CONCEPTUAL DESIGN

This portion of the report deals with the design concepts necessary to utilize a screening/flotation system on a full scale basis for treating combined sewer overflow. It is not the intention of this discussion to provide specific answers to all design details. Sufficient information will be presented to form a basis for process design. Various engineering considerations and/or judgements must be provided to produce the final overall system design.

The overall system can be divided into various subsystems and these subsystems are listed and discussed below:

1. Pumping system
    a. Self cleaning bar screen
    b. Pump pit
    c. Variable rate pumping system

2. Screening/flotation system
    a. Drum screens

Table 17. SUMMARY OF DISINFECTION DATA

Run no.	Chlorine dosage, mg/l	Point of addition[a]	Detention time, min	Influent Coliform per 100 ml x 10^5	Effluent Coliform per 100 ml
695	10	PF	20	36	<100
696	10	PF	20	5.7	<4
697	10	PF	20	1.3	<4
698	8	PF	20	7.8	<4
699	10	PF	20	6.2	2
6910	10	PF	20	19	<2
6911	10	PF	20	20	10
6912	10	PF	20	65	<5000
6913	10	PF	20	38	<5000
6919	10	EFF	10	310	60,000
6920	10	EFF	10	160	40,000
6921	10	EFF	10	55	<7
6922	10	EFF	10	82	15,000
703	10	INF	21	270	<1000
704	10	INF	21	12.2	<100
706	10	INF	21	0.7	200
707	10	INF	21	340	3800
708	10	INF	21	110	18,000

a. PF = Chlorine added in pressurized flow line
EFF = Chlorine added to effluent from flotation basin
INF = Chlorine added to raw waste prior to bar screen

Note: Samples were dechlorinated when necessary using Na_2SO_3.

    b. Pressurized flow system
    c. Sludge collection
    d. System tankage
    e. Flocculators

3. Solids slurry storage
    a. Mixers
    b. Transfer system
    c. Dewatering (if required)

4. Chemical addition
    a. Chemical storage
    b. Mixing system
    c. Metering pumps
    d. Disinfection

PUMPING SYSTEM

The pumping system is obviously a vital subsystem in the overall treatment concept. It is envisioned that a sump will be utilized to provide the necessary pump suction conditions. A self cleaning bar screen will be utilized just up stream of the sump to remove large objects which will not pass the pumps and/or could cause problems down stream in the treatment system in such areas as the drum screens or sludge removal systems. Bar spacing is recommended at 1/2" as this value proved adequate in the demonstration system. A medium duty bar screen will have sufficient strength to handle the imposed solids loading.

The pumping system must be able to handle the variable rates which will be encountered during operation. The pumps therefore must be controlled automatically to vary the pumpage as the raw flow varies. There are numerous pumping system configurations of this type which have been employed in the past for storm water pumping, municipal waste treatment and industrial processing. Many pump manufacturers offer package pumping systems (69) which would meet the required design considerations. Therefore no detailed information on pump station design will be presented herein.

It should be noted however that open type screw pumps seem to be ideally suited to combined sewer overflow treatment systems, since they can provide variable flow rate from a constant speed motor. Since any system must be designed for a specific hydraulic flow rate, an overflow structure should be provided for the pumping system. Considerations involved in overflow design should include utilization of the sewer system for maximum storage of raw overflow. This will provide a damping effect on the raw flow rate, and minimize control problems in the treatment system. Proper design of the overflow will provide satisfactory treatment system operation with a minimum of excess overflows. Provisions should also be made for sump cleaning, since large volumes of gravel and grit are anticipated. Overall pump system design should provide for ease of cleaning and maintaining the pumps. No problems were encountered during operation of the demonstration system with regard to feed pumps. The demonstration system, however, had only a single feed pump and the flow rate did not vary during operation. Since the screening/flotation system can function at overflow rates higher than the design value, the pumping system should be designed with this fact in mind and sufficient capacity should be provided. A pumping capacity of one and one-half the flotation design capacity should be provided, since the flotation unit can handle this additional volume for short periods with only moderate decrease in removal efficiencies.

It may be possible in some applications to utilize gravity flow. In this case only sluice gates will be required to direct the raw flow to the various screening/flotation modules. The gates should be automatically positioned to provide proper control. Consideration of head loss across the screen becomes more critical when contemplating a gravity feed design. It may also be possible in some applications to utilize gravity feed and effluent pumping. This approach should provide the most maintenance free pumping system since the effluent water will be low in suspended solids. When gravity feed systems are utilized, a sump or stilling basin will still be required to provide proper hydraulic control, and the bar screen is also required for system protection. Grit accumulations are expected to be greater in the gravity flow systems, since turbulance from the pump suction will not be present.

SCREENING SYSTEM

The screening system consists of basically two sections, the drum screen and the backwashing system. The critical design parameters associated with the drum screen include hydraulic loading, solids loading, and head loss capability. The hydraulic loading is a function of the wetted screen area. This area varies only slightly as the head loss across the screen increases during operation. The hydraulic loading is not affected by rotation speed. Generally a drum screen can operate with up to 70% of the screen surface submerged. Higher submergence is not recommended due to possible flooding of the backwash water removal hopper. Hydraulic loading in the range of 25-45 gpm/sq ft of screen area was utilized in the demonstration system for a 50 mesh, 297μ opening, screen media. A hydraulic loading of 40 gpm/ft^2 and a screen size of 50 mesh are recommended at this time.

Drum rotation speed controls the solids loading on the screen. It was found during this study that a solids loading of 1.2 pounds of dry solids removed per 100 sq ft of screen media produced a head loss of about 13 inches of water. Drum rotation speeds were in the range of 1 to 5 rpm. Solids loading may be calculated with the following equation:

$$L_s = F_s R / r A_D$$

where:

L_s = Solids loading per 100 sq ft

R = Screen removal efficiency (%)

F_s = Feed solids into screen (lbs per min)

r = Drum rotation speed rpm

A_D = Total surface area of screen

As may be seen from the equation, solids loading is directly proportional to solids removal efficiency and inversely proportional to drum rotation speed. A removal efficiency (R) of 35% is recommended based on the results obtained in the demonstration unit. Drum rotation speeds of 2 to 12 rpm are also recommended.

It is apparent that selection of drum area is controlled by two criteria; hydraulic loading and solids loading. Either of these two variables may control the screen area requirements. If a solids loading of 1.2 lbs per 100 sq ft is utilized, resulting head losses will be in the range of 12 to 14 inches of water. Higher head losses and subsequently higher solids loadings may be possible without a significant effect on process efficiency. The inside of the drum should be fitted with an angle iron system (similar to a roto-dip feeder), which will pick up any solids which will not adhere to the screen media and would not be carried up to the spray washing system.

The screen cleaning system consists of a pump, a header system and spray nozzles. A hopper inside the drum collects the material as it is flushed from the screen. Required screen wash water rates amount to 15 gpm per foot of drum length. This volume is sufficient to clean a completely blinded screen. The spray nozzles utilized should provide a low mechanical pressure on the screen media, but still provide good washing capability. The nozzles should have as large an opening as possible consistent with a good spray pattern. The nozzles utilized on the demonstration unit had egg shaped openings with the smallest dimensions being 1/4 of an inch. They were positioned about 12" from the drum surface and provided excellent cleaning capability. They exerted an average pressure of less than 1 psi on the media.

Some problems were encountered with nozzle plugging due to an inefficient seal between the raw and screened water. Plugging occurred mostly from gravel or grit with some plugging due to string and twigs. The drum seal has subsequently been improved, but to eliminate a possible plugging problem, a small wet cyclone (six inch diameter) should be utilized to trap any material which could cause plugging. The dirty water discharge from the cyclone should be routed back through the screen.

It is recommended that screen rotation be continuous. This eliminates rapid change in head loss when the clean screen enters the water, which could result in an incomplete washing cycle. If the drum were stationary, the portion of media not in contact with the flow would initially be clean. As the head loss reached the limit of the backwash actuating system and the drum was activated, it would rotate only until sufficient clean screen area was wetted to reduce the head loss to normal values and the washing system would then be deactivated. This could leave portions of the screen unwashed and cause rapid head loss fluctuations. When the rotation is continuous, a solids layer gradually builds up over the entire drum surface. The back wash system is then activated and cleans the entire screen before deactivating. It is recommended that the spray water cleaning system be activated by monitoring differential pressure, i.e. head loss across the screen. Conductivity probes can be utilized, and there are a number of commercially available, inexpensive units on the market. The system probes are mounted in the tank at the desired differential elevation. When the water contacts both probes, a relay is tripped which can be used to activate the backwash pump. The relay remains closed until the water level is below the lower probe. The differential chosen should be about 50-60% of the expected head loss across the screen, i.e. for a 2' head loss the spray system should activate at 1 to 1.2 foot of head loss. This prevents the screen from becoming completely blinded prior to activation of the back wash system. The lower probe should be set two to three inches higher than the head loss level when the screen is completely clean. This will prevent unnecessarily long back wash cycles.

The media utilized in the demonstration system was type 304 stainless steel. This media proved adequate. Because of the near neutral pH encountered in the demonstration runs (6.8 - 7.5), brass screen which is considerably less expensive could be utilized. During the two years of operation reported herein some bacterial growth on the screen has been experienced. It was found that a rinsing with chlorine solution would remove these growths.

The control of the feed water flow into the drum screen is extremely important. The possibility exists, with this highly variable raw waste, that the head loss capacity of the screen may be exceeded during the heavy solids loading peaks. The system should therefore have an automatic bypass feature, which will allow relief of the screen if the head loss capacity is exceeded. The water which is bypassed during these times can be routed to the flotation zone. It is also recommended that a head loss capacity of 24 inches of water be provided.

Figure 18 presents a sketch of the recommended screen configuration. This sketch illustrates the important features of the screen installation which have been discussed above.

FLOTATION SYSTEM

The design of the flotation system requires the consideration of the following components: pressurized flow system, flotation basin and scum removal

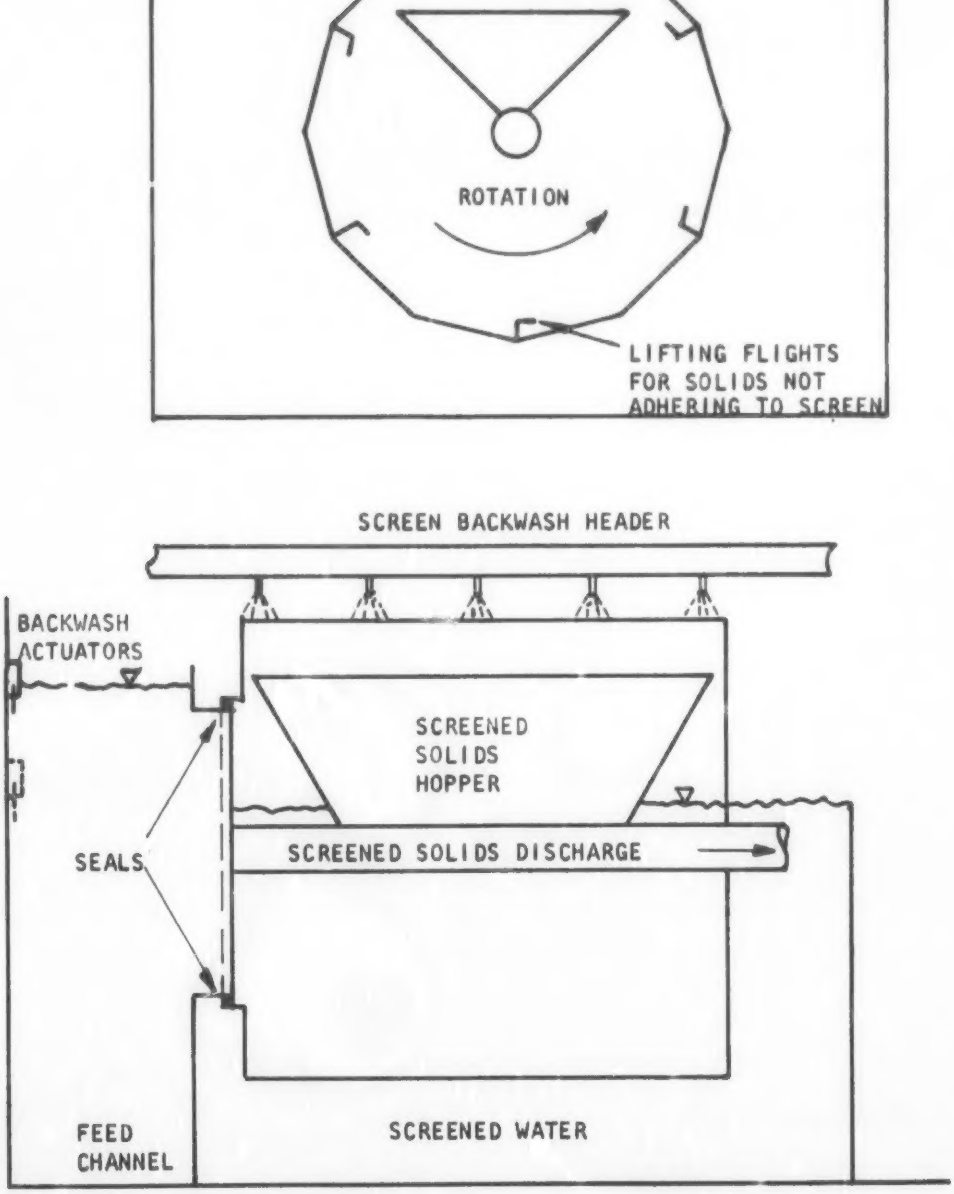

Figure 18. Recommended screen arrangement

system. Details on design recommendations will be discussed in this section along with a proposed system arrangement.

The pressurized flow system is the heart of the dissolved air flotation process. It includes a pump, air solution tank, pressure reduction valve, source of compressed air and suitable control systems.

The pressurized flow system should be designed to provide a volume equal to 30% of the raw flow rate into the system. This should provide an adequate margin of safety since testing at the demonstration site indicated 20% was sufficient. The recommended design operating pressure is 50 psig. The air solution tank should provide maximum air water interface to obtain higher air solution. Some air solution tanks are packed with a tower packing to provide this interface. For treatment of combined overflows, however, a packless tank is recommended. A packed tank would be very susceptible to plugging due to the solids present in the waste stream. Packless tanks are generally fitted with an internal baffle to promote air water interface. Nominal detention time in the tank is generally in the range of one minute. The tank should also have some method of controlling the water level, since only about 20% of the tank volume is filled during operation.

The pressure in the system is controlled via an adjustable valve. Weir type valves have been utilized successfully. The valve is positioned by way of a pneumatic controller which allows automatic control of the system pressure. The valve, besides providing pressure control, provides the necessary shear forces to promote proper bubble formation.

The sizing of the flotation basin is based mainly on the American Petroleum Institute (API) standards (64). Based on operation of the demonstration system, some modifications have been made to this procedure. The API design criteria are listed below as follows:

$$L = 1.2\ FV_h d/V_t$$

Where: L = effective tank length (ft)

V_t = rate of rise of particles (fpm)

V_h = horizontal velocity in tank (fpm)

d = effective tank depth (ft)

$F = (0.026\ V_h/V_t) + 0.995$

V_h maximum = 15 V_t or 3 fpm

t_D (tank detention) = 10 minutes minimum

d (depth of tank) = 0.3 to 0.5 of tank width

minimum depth = 3'

The particle rise rate can also be expressed as a surface loading rate, i.e.,

$$S_L = (V_t)7.48$$

where S_L = surface loading gpm/sq ft and V_t is in fpm

The demonstration system design was based on the API procedures listed above. A particle rise rate of 0.4 fpm (S_L = 3 gpm/sq ft) was utilized based on laboratory tests. The tank was also designed to allow changing the overflow rate. It is obvious from the above discussion that the particle rate of rise is critical in the flotation basin sizing. It may also be seen that the horizontal velocity will be at the maximum value (3 fpm) for all rise rates in excess of 0.2 fpm. The particle rise rate is dependent upon particle diameter to the second power and the apparent difference in density of the particle bubble combination and suspending fluid to the first power. Little can be done to control the latter, but the particle size can be significantly affected by proper chemical addition and flocculating procedures. Rise rates as great as 5 fpm have been obtained in the laboratory, indicating large floc particles can be developed. It is recommended that the above discussed procedures be utilized to size the flotation basin. A particle rise rate of 0.45 (S_L = 3.3 gpm/sq ft) should be utilized.

Overhead skimmers are provided to remove the floated scum. Bottom skimmers are sometimes utilized on flotation systems to remove any sludge which may possibly settle. If screening (50 mesh or finer) is utilized in the system, bottom skimming is not recommended since the small amount of settled sludge expected can be removed while draining the tank between storms. If, however, flotation is utilized without screening, bottom skimming will be required. Removal of scum should be controlled by a timed cycle or the sensing of a sludge blanket. This will allow sludge to be removed only when required and hold to a minimum the volume of floated scum which will require ultimate disposal.

The recommended general arrangement for the screening/flotation system is presented in Figure 19. It is felt that this configuration will meet all process requirements and be the most economical system.

The additional subsystems required to complete the treatment system are sludge storage and the chemical storage and feeder units. A possible overall site arrangement including these subsystems is shown in Figure 20. Sludge storage should be sufficient to handle 2% of the raw flow for the design storm period. This should provide sufficient storage volume, however, the ultimate sludge disposal method may dictate the desired storage volume. Sludge disposal alternatives available include tanker trucking, providing a truck mounted vacuum filter to reduce the slurry to a cake for hauling, or disposal by pumping to an interceptor sewer for transporting to the sewage treatment plant. If the latter method is used, the interceptor obviously must not have possible overflow points

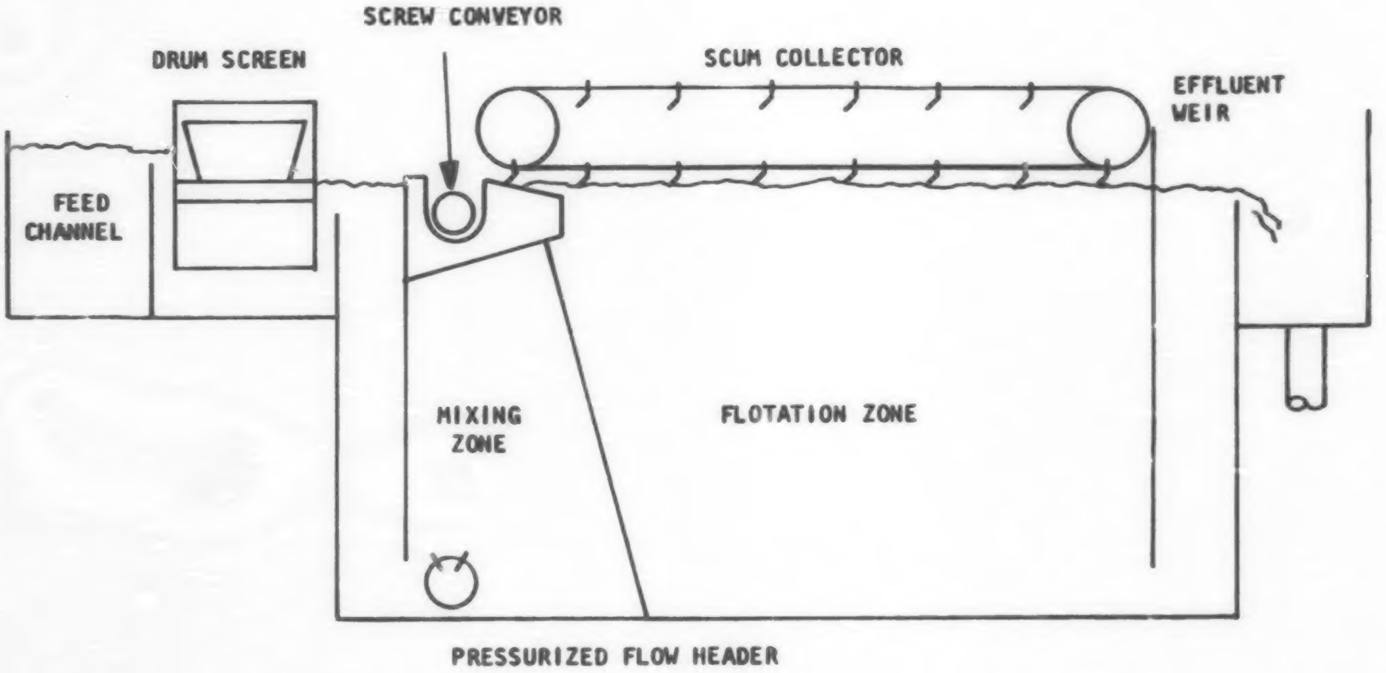

Figure 19. Recommended screening/flotation arrangement

in its course to the sewage treatment plant. If disposal via interceptor is utilized, a sludge pump will be required and essentially no solids storage pit will be necessary. On the other hand, if it is not feasible to pump solids into the interceptor during a storm, they may be stored at the site and pumped to the interceptor after the storm has passed. Regardless of which method is selected, proper attention should be given to the problems associated with handling sewage solids slurries.

The chemical treatment module (Figure 20) should provide for storage of flocculating chemicals (ferric chloride and a polyelectrolyte) as well as chlorine. A sufficient supply of chemicals consistent with the requirements of the system should be provided. Estimated chemical dosages are: ferric chloride - 20-25 mg/l, polyelectrolyte - 5 mg/l, and chlorine - 10-15 mg/l. The chemical treatment module also houses the proper feeder systems to accurately dispense the chemicals into the wastewater flow.

The entire system detailed in Figure 20 should be automated 100%. This will allow remote monitoring and control of the treatment facility at a central location. However, the maintenance involved with automatic systems which are used intermittently will have to be tolerated. It is felt that this maintenance will not be of such a magnitude to negate the advantages of automation.

ECONOMIC CONSIDERATIONS

There are many factors which must be considered when estimating the capital costs of a combined sewer treatment facility. The basic areas of consideration for a screening/flotation system are listed below:

1. Screening/flotation system including
    - self cleaning bar screen
    - variable rate pumping system
    - solids storage and disposal
    - instrumentation
    - control building
    - erection costs
2. Sewer interconnection (i.e. combining a number of overflow points to reduce the number of treatment sites) and outfall facilities
3. Land costs
4. Special design problems
    - foundations (soil problems)
    - ground water
    - special construction techniques
    - freezing problems
5. Engineering costs and fees

The total installed cost for the demonstration facility was approximately \$90,000 (1968) or \$18,000 per MGD capacity for the 5 MGD plant. It should be noted that the demonstration system did not have a self cleaning bar screen, a variable rate pumping system, or solids storage facilities which would increase the cost per MGD capacity. On the other hand, the demonstration system was of all steel construction and only 5 MGD capacity. A larger cap-

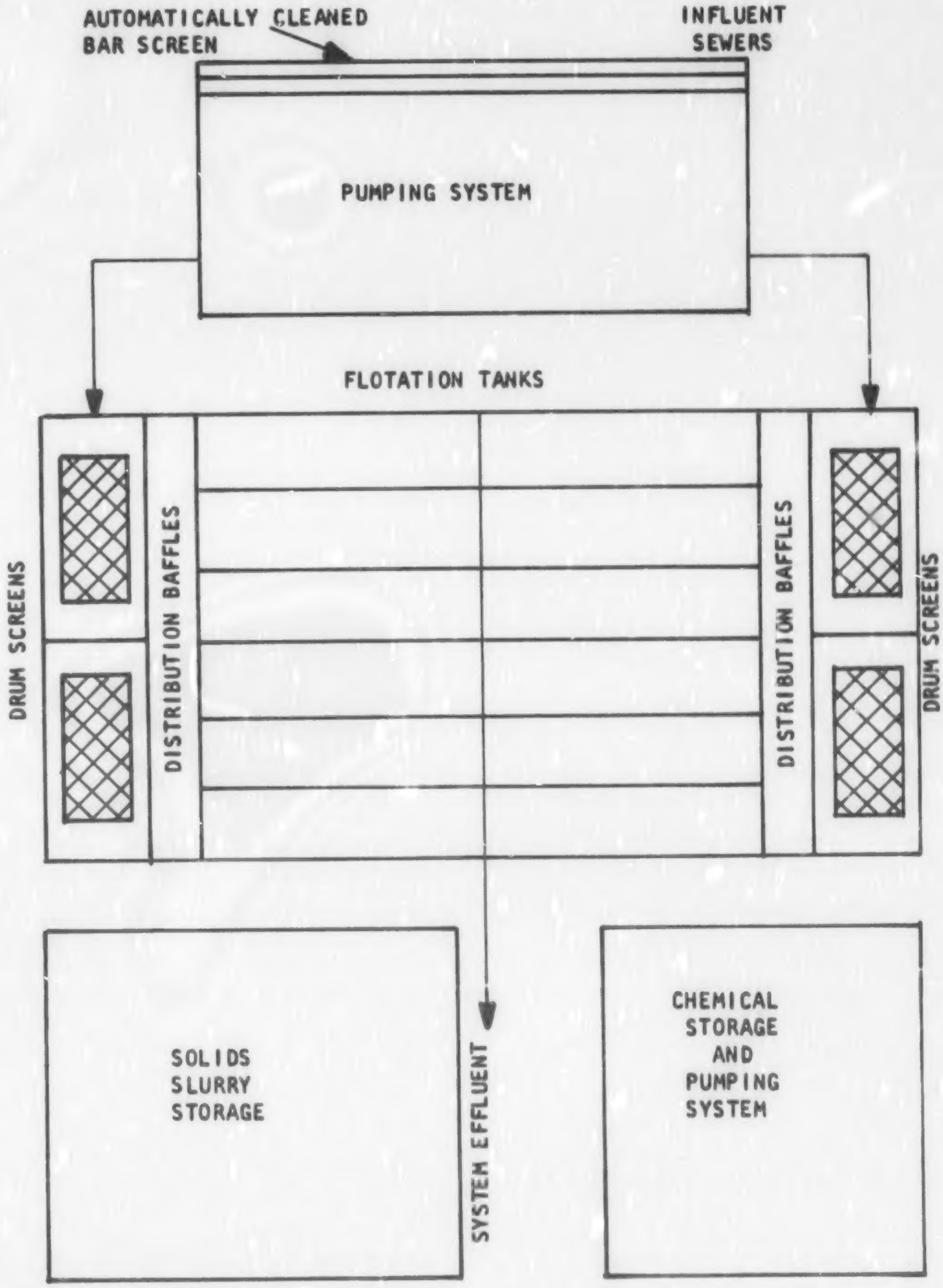

Figure 20. Overall system configuration

acity and concrete construction are expected to decrease the cost per MGD capacity.

Based on the above generalized information, the cost of providing a screening/flotation system to treat the entire Hawley Road drainage area (~500 acres) is presented below. It was assumed that the design storm was the once in 5 year storm. From Milwaukee rainfall records this intensity is approximately 1.0 inch per hour for the estimated time of concentration of the drainage area of 100 to 110 minutes. This amounts to an overflow rate of approximately 120 MG. Allowing a 33% surge factor for this peak storm results in a design capacity of 90 MGD. The following costs are estimated for this system capacity.

1.	Screening/flotation system	$1,350,000
2.	Sewer interconnection and outfall facilities	$ 65,000
3.	Land costs (1.5 acres @ $100,000/acre)	$ 150,000
4.	Special design problems	$ 90,000
5.	Engineering costs and fees	$ 240,000
	Total	$1,895,000
	Cost/MGD	$ 21,056
	Cost/acre	$ 3,828

A detailed design and cost estimate for a midwest city indicated a system cost of $22,000 per MGD capacity which compares favorably with the above estimate for the Hawley Road drainage basin.

The operating costs for a screening/flotation system include power, chemicals, and maintenance. Table 18 presents a summary of the estimate operating costs. The total operating cost is 3.09¢/1000 gallons of treated overflow. The majority of this cost is for chemical addition, i.e. 2.51¢/1000 gallons. These costs are based on operation of the demonstration system at Hawley Road and are not expected to vary significantly with plant size.

Table 18. OPERATING COST ESTIMATES

Item	Quantity	Unit cost	Cost, ¢/1000 gallons
Power	15 KW/MGD	1.5¢/KWH	0.54
$FeCl_3$[a]	20 mg/l	4.5¢/lb	0.75
Polyelectrolyte[a]	4 mg/l	35¢/lb	1.17
Chlorine[a]	15 mg/l	4.7¢/lb	0.59
Labor[b]	30 hr/mo	$10/hr	0.02
Parts[b]	$300/mo	---	0.02

Total cost = 3.09¢/1000 gal.

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a. Based on carload prices
b. Based on 90 MGD system 40 hours per month operation

SECTION VIII

DESIGN AND CONSTRUCTION OF THE 5 MGD SEQUENTIAL SCREENING DEMONSTRATION FACILITY

LOCATION OF THE SITE

The location of the site for the sequential screening treatment system is the same as the site for screening/flotation system, i.e. The Hawley Road Site. A detailed description of this site has been included in Section V of this report on screening/flotation treatment of combined sewer overflows. Briefly, the total drainage area served by this sewer is 495 acres consisting predominantly of developed residential housing. Of this drainage area, 42% was determined to be impervious. There is very light commercial usage and no heavy industry within this area. The drainage area contributing to Hawley Road combined sewer overflow is shown in Figure 2.

TREATMENT SYSTEM COMPONENTS

A flow schematic of the 5 mgd sequential screening treatment system utilized is shown in Figure 21. Also, two photographs of the overall treatment system are shown in Figures 22 and 23. The treatment process consists of passing the raw combined sewer overflow, sequentially, through a series of screens of varying size openings. The raw waste is first passed through a 1/2" bar rack. The purpose of this bar rack is to remove large objects which may clog or damage the finer mesh drum screens. The flow then passes through a series of three drum screens, with openings varying from coarse to fine. The coarse, medium and fine screen openings selected for this study were: 20 mesh (841 microns), 100 mesh (149 microns) and 230 mesh (63 microns) respectively. The drum screens are contained in basins of steel construction and are cleaned with spray backwash nozzles. The water utilized for the spray backwashing is the screened effluent from the respective drum screens. The captured solids from each screen are discharged to a sanitary sewer located at the site. The treated effluent is discharged directly to the Menomonee River.

The series screening system is designed for a maximum hydraulic capacity of 5 MGD. The system can be operated either in parallel or in series with the screening/dissolved-air flotation treatment facility. Provisions are made for adding flocculant aids and disinfectant to the waste flow at various points as shown in Figure 21. The entire system has been automated for start up, sampling and flow monitoring with the exception of backwash waste sampling.

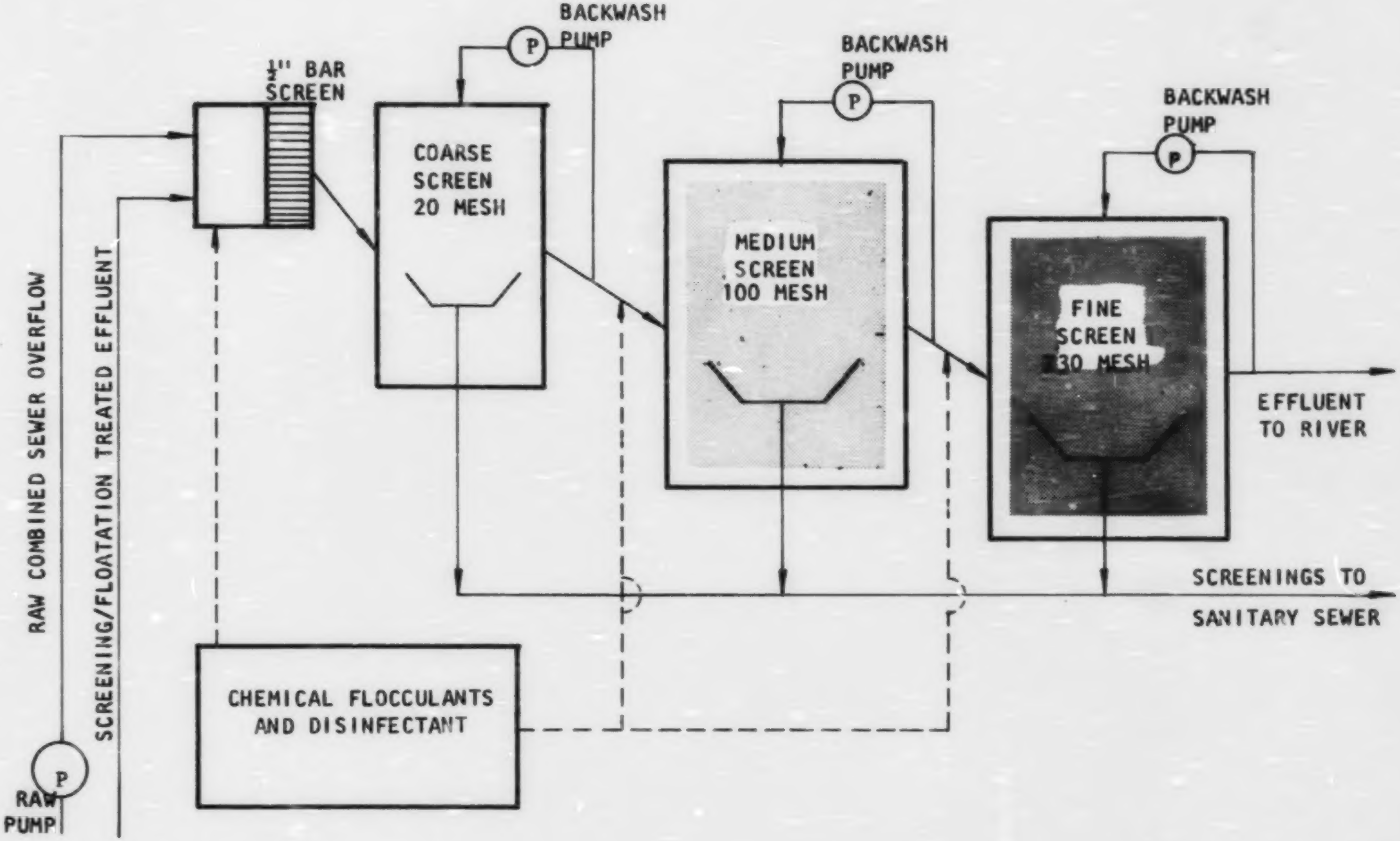

Figure 21. Schematic flow sheet for sequential screening treatment system

Figure 22

Figure 23

Sequential screening demonstration system

DESIGN OF THE SCREENING SYSTEM

The screening system consists of basically two sections, the drum screens and the backwashing system. The entire design of the screening system was based upon the data generated and the experience gained from the operation of the existing screening/flotation treatment facility. The critical design parameters associated with the design of the drum screens include solids loading, hydraulic loading, and head loss capability. A solids loading of 1.4 lbs/100 sq ft was selected. Drum rotation speeds were in the range of 1 to 7 rpm. As mentioned earlier, the screen openings selected for the three drum screens were: 20 mesh, 100 mesh and 230 mesh. These openings allowed high hydraulic through-put rates of the order of 50 gpm/sq ft for 20 mesh screen and up to 30 gpm/sq ft for the finer screens at reasonable headlosses. A maximum headloss capability of 24 inches and a maximum screen surface submergence of 75% were provided in the design of all the three drum screens. The screen material utilized was 316 stainless steel in square weave mesh. The backwash pumps were sized to provide minimum screen wash water rates of 15 gpm per foot of drum length. The nozzles utilized were spaced 6" apart and were designed to exert an average pressure of less than 1 psi on the media.

Each screen is an open ended drum into which the waste water flows (Figures 18 and 24). The water passes through the screen media and into a screened water chamber directly below the drum. The drum rotates and carries the removed solids on top of a hopper into which the solids fall by gravity or are flushed from the screen by a spray water cleaning system (Figure 18.) Those solids which will not adhere to the screen media are picked up by angle iron sections which act similar to a trough or a roto-dip feeder and are thus removed from the flow. Screened water from each drum screen is used for the backwashing of the respective screen. The spray water cleaning is controlled by liquid level electrical probes located in the screen chamber. The probes are set to actuate at a headloss of 12" of water through the screen (Figure 25). The resultant solids slurry is then routed to a sanitary sewer.

More photographs of the screening system showing the screens, the drives and the backwashing systems are shown in Figure 26. The basic screen is fabricated from mild carbon steel. The screen backing material is a perforated metal plate 3/4" x 3/4" on 7/8" centers. This provides 73% open area and only a minimum of flow restriction. The rotation of the drum screens is continuous. The drum rotation speed is controlled by a variable speed drive which is positioned manually. The screened water was initially sealed from the raw waste by a single lip extruded rubber seal fastened between the end of the drum and a stationary ring. However, sealing problems were immediately apparent during the monitoring of the first overflow with the above described seals. It was found that the rubber seals buckled and overturned backwards from the water pressure. This in turn caused leakage of the influent water into the screened water compartment. A new seal design was then incorporated for all the three screens. The new seal was an X-shaped extruded plastic which could be compressed between the end of the drum and the stationary ring. The seal was also wired to the stationary ring at 12" intervals to hold it in place. This arrangement eliminated all leakage problems and provided an excellent sealing between the influent and the screened water.

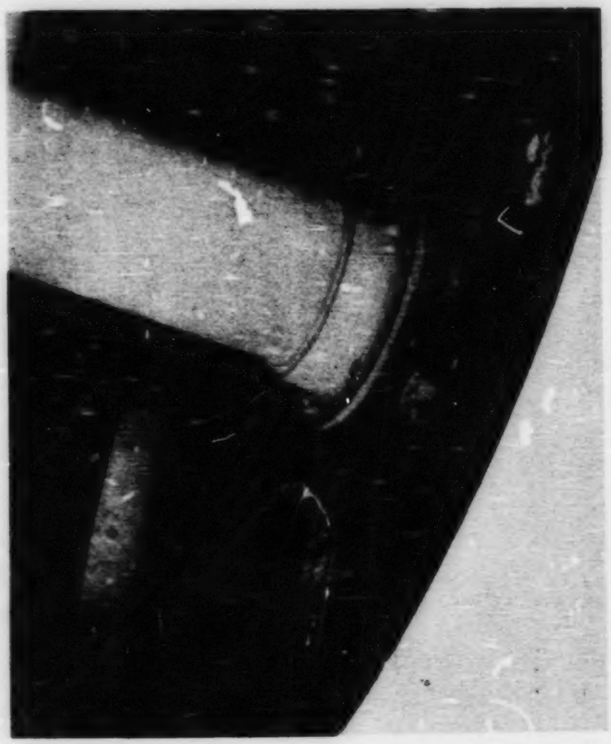

Figure 24. Open end of the screen

Figure 25. Liquid level electrical probes

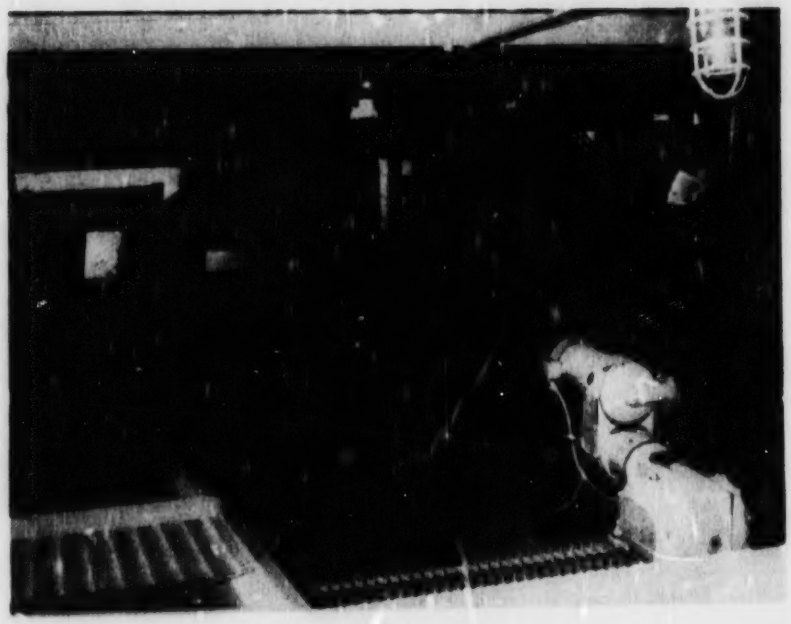

Figure 26. Screening system

The backwashing system consists of a pump, a header system and spray nozzles. The nozzles utilized for the demonstration unit had egg-shaped openings with the smallest dimensions being 1/4 of an inch. They were positioned about 12" from the drum surface at 6" intervals and provided excellent cleaning capability. To eliminate possible plugging problems of the nozzles, the screened water utilized for the backwashing is passed through a small, wet cyclone (6" diameter) for the coarse screen and through 1/16" mesh strainers for the medium and fine screens. Such provisions can trap any large materials that may overflow into the screened water chamber when the headloss capability on the upstream screen is exceeded.

As indicated earlier, the maximum headloss handling capability of the drum screens is 24". Any excess headloss will allow some unscreened water to enter the screened water chamber. The overflow on the coarse and the medium mesh screens will only act as the influent to the downstream screen, but if the headloss capability is exceeded on the third and the finest screen (230 mesh) the overflow mixes with the final effluent affecting its quality. During some runs with extremely heavy solids loads, the headloss capacity of the screens was exceeded, which will be discussed later.

The drum screens as installed are 12 sided drums with effective diameters of 8 ft. The length of the coarse screen is 4.5 ft and of the other two finer screens is 7 ft. The 8 panels for each screen are 2 ft wide and run through the length of the drum screens. The maximum wetted screen areas for the three screens are: 76 sq ft for the coarse screen and 123 sq ft each for the medium and fine screens.

DESIGN OF SUPPORTING SYSTEMS

The appurtenant equipment and tasks necessary to provide a functional demonstration system included site preparation, construction of a manhole and pumping sump, selection of the necessary flow metering equipment and chemical feed system, and design of suitable electrical and pneumatic control systems.

The site location and the retaining structure to allow a limited impoundment of the flow have been discussed earlier. Site preparations involved laying a concrete slab to provide support for the system tankage. A manhole was constructed as well as a pumping sump, directly in the combined sewer. A centrifugal pump was selected for transporting the CSO from the sump to the demonstration unit. A vacuum pump was also provided to prime the raw feed pump. Photographs of the raw pumping system and the influent channel of the treatment unit are shown in Figure 27. Flow metering equipment is provided to measure the influent flow rate and the volumes of screen backwash water for the three drum screens. Both these flows are measured via venturi meters connected to differential pressure gauges which both record and totalize the flows. A positive displacement, triple head chemical metering pump is provided to add flocculating chemicals and disinfectant. The electrical control panel is equipped with all necessary controls for 100% automatic operation with manual overrides on all systems. Photographs of the control shack housing the control panel, flow meters, chemical pump and the vacuum pump are shown in Figure 28.

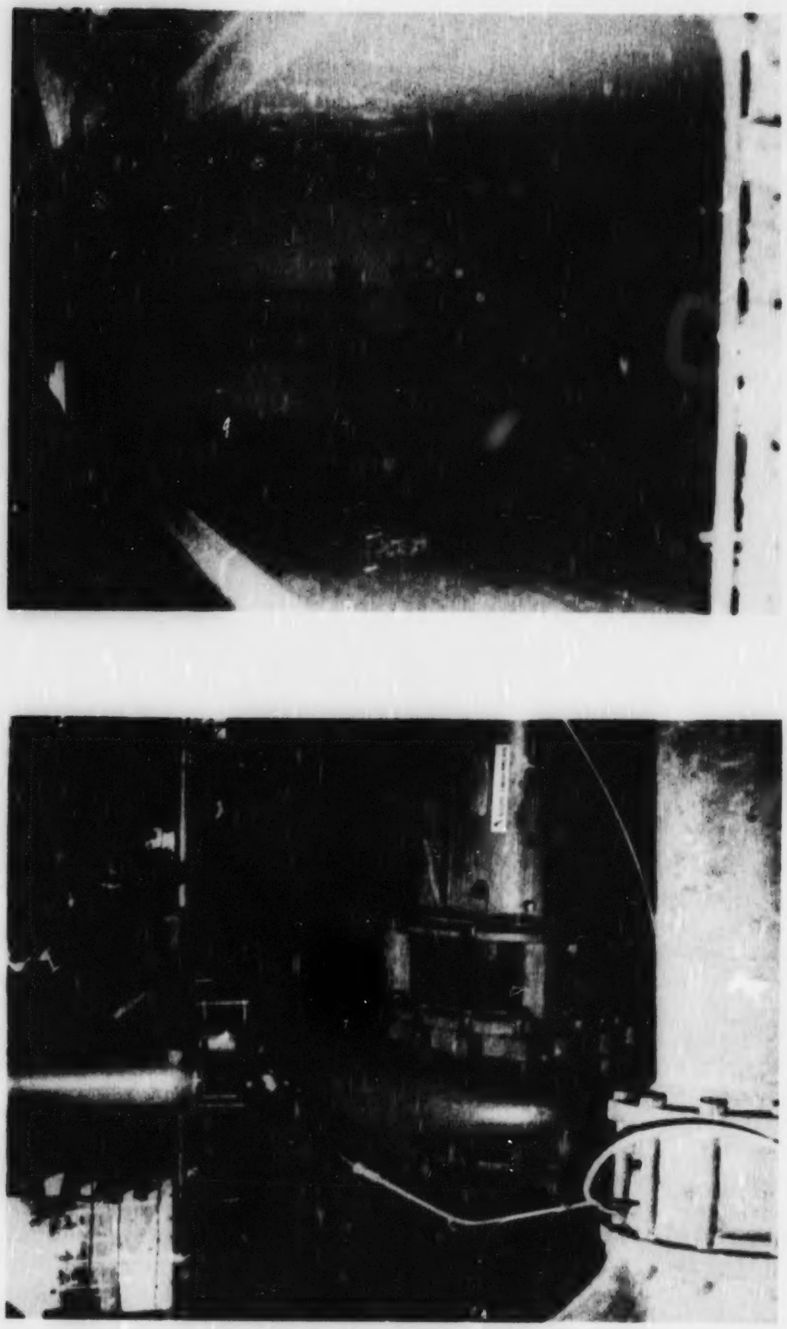

Figure 27. Raw feed system

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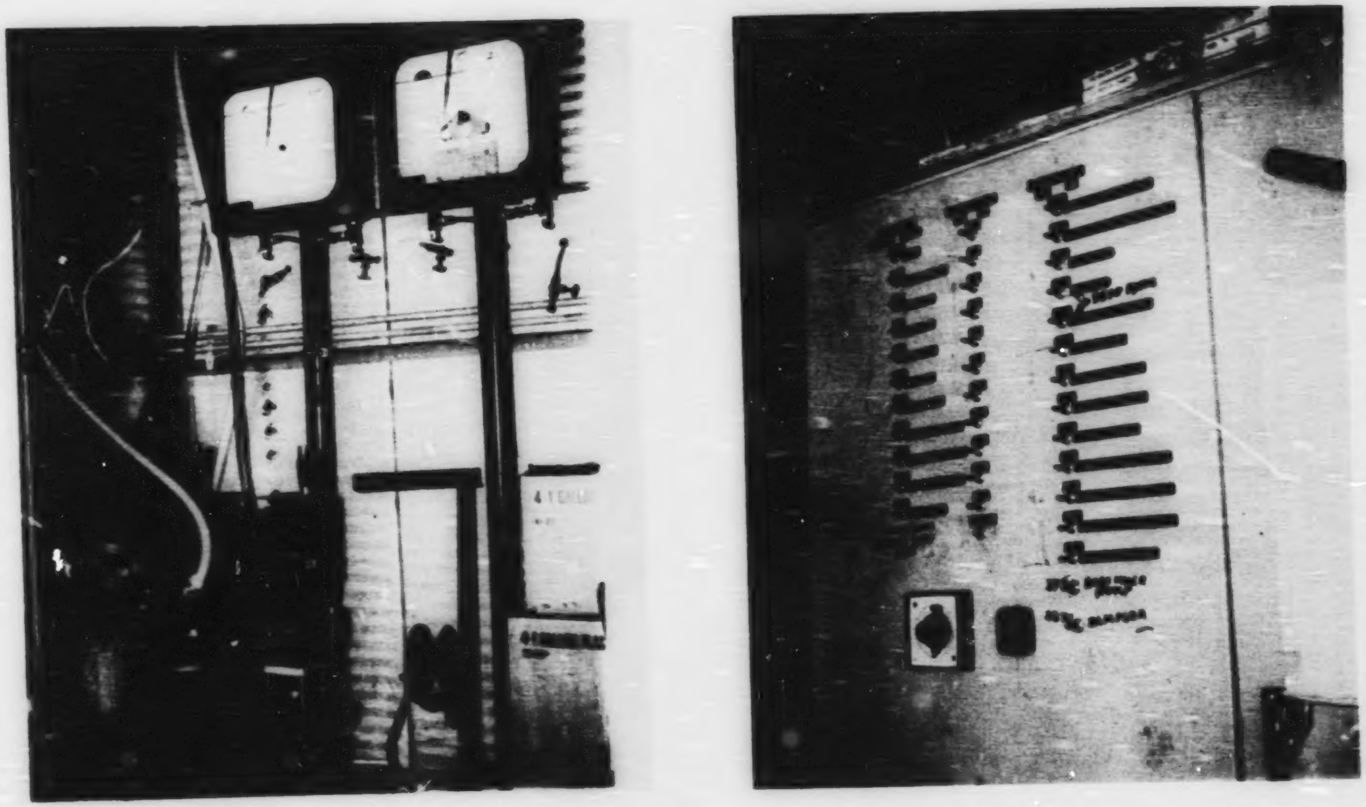


Figure 28. Interior view of the control shack

A transfer pump and a pneumatic flow rate controller are provided to transfer the flotation treated effluent to the sequential screening system. Influent channel wall between adjacent drum screens can be removed to provide maximum flexibility in operational modes. The test plan, operation modes, and sampling procedures will be discussed later. A merchant police alarm is connected to the system so that personnel will be alerted when the system goes into operation. The system is always (24 hours per day, 7 days per week) ready to operate; and hence, the maximum possible number of overflows can be monitored.

SECTION IX

SEQUENTIAL SCREENING OPERATING RESULTS (1971) AND DISCUSSION

OPERATIONAL METHODS AND PROCEDURES

The demonstration system previously described in Section VIII was put into operation in early October, 1970. However, drum screen sealing problems (also discussed in Section VIII) necessitated a new design of the seals. This problem coupled with dry weather did not permit any further operation of the screening facility during the remainder of the 1970 operational season. Data reported herein was taken during the 1971 operational season between May and October. During this period 21 overflows were monitored with the screening system. The system was put into operation automatically when a conductivity probe in the sewer sensed an overflow. The drum screens were immediately put into operation as the raw feed pump began to prime. The raw feed pump was generally primed in about 7 - 10 minutes. On priming, the raw pump is activated and the flow meters and the chemical feeder (if utilized), along with the sampling system and the backwashing system (operates only when the headloss across the screen reaches a pre-set level), were placed into operation. At the end of the overflow, the system shut down automatically. The screened water chambers were then drained out manually through the backwash pumps. The controls were subsequently positioned for regulating desired variables for the next run. The variables associated with the screening operation include raw flow rate, drum screen speeds, backwashing rates and chemical dosages.

SAMPLING PROCEDURES

The sampling system consisted of two timers connected through the proper valving, to automatically composite the raw waste and the screened effluent samples. The first timer controlled the sample taking frequency (0-30 minutes). The second timer controlled the duration of sampling time (0-60 seconds). Generally, the samples were composited every five minutes with the automatic system throughout the duration of the overflow. The sampling valves were air operated weir valves.

Sampling began after the raw pump was primed. The first samples of the raw and screened effluents were collected only after a minimum of 5 minutes of system operation had elapsed. The time interval was sufficient for filling water in the screening chambers and insured collection of representative effluent samples. Screen backwash samples from the various screens were collected manually during the backwash periods. These samples were not automated due to the problems associated with intermittent flows and heavy solids concentrations in these process streams.

Separate samples of the composited final effluent were normally taken out at the end of each overflow for total coliform analysis. These samples were placed in bottles containing excess sodium thiosulfate to allow purging of any residual disinfectant (chlorine). Later in the study, it was felt that the coliform count results from the composite samples may not be truly representative of the actual disinfection efficiency due to any disinfection provided by the residual disinfectant during the period of sample collection. To overcome this problem, two types of effluent samples, instant and composite, were analyzed for total coliforms. The instant sample referred to a grab sample of the screened effluent while the composite sample referred to the one which was taken at the end of the overflow from the composited (through the duration of the storm) final effluent. Both these samples were then placed in bottles containing sodium thiosulfate to purge any residual chlorine. All samples were refrigerated immediately after each run. Analyses were then started within 0-8 hours. Sample analysis procedures are discussed in Appendix C.

TEST PLAN

The variables that needed to be evaluated and optimized for the operation of the sequential screening facility include: screen openings, screen media, sequential arrangement of screens, hydraulic loading rates, solids loading rates, backwashing rates and addition of chemical flocculants. During the first operational season the test plan was designed to study only the hydraulic and the solids loading rates by assuming the other variables. Also, initially, the sequential screening system was operated in parallel to the screening/flotation system and the following flow routing path and design parameters were selected:

Flow Routing Path: Raw → Bar Screen → Coarse Screen → Medium Screen → Fine Screen

Screen Media: 316 stainless steel
Bar Screen Openings: 1/2 inch
Coarse Screen Size: 20 mesh (841 micron)
Medium Screen Size: 100 mesh (149 micron)
Fine Screen Size: 230 mesh (63 micron)
Chemical Flocculant Addition: None
Backwash Rates: As needed

The variations in the hydraulic loading rates could be achieved by varying the flow rates and in solids loading rates by varying the drum speed rotation and/or by blanking out portions of the drum screening areas. It was planned to obtain 5 to 6 runs for each variable combinations of the test conditions at high and low values.

However, from the operation of the first few runs, it became apparent that it was not possible to operate the field unit under pre-set conditions for varying the solids loadings because of the variability of the CSO quality. Also, the particulate pollutant removals on the screens were significantly lower than expected. Therefore, the test plan was modified to provide the best possible test conditions that may improve the final effluent quality. These changes in the test conditions included: lowering of the raw flow rates to decrease the hydraulic loadings, increasing the drum rotation speed and providing maximum available screening surface area to decrease the solids loadings and adding cationic polymer flocculants at different treatment points. These conditions were changed in the field whenever possible to provide maximum information with the limited number of overflows occuring during the 1971 operational season.

RAW WASTEWATER QUALITY

A total of 21 overflows were monitored on the sequential screening system during the 1971 operational season. As expected, the quality of the combined sewer overflow from the Hawley Road sewer varied widely (Table E-16, Appendix E). However, the extremely high pollutant loaded first flushes, reported in an earlier report on screening/flotation treatment (70), were not distinguished separately. Instead, each overflow was counted as a separate event over the entire length of the system operation. This change was made to reduce the number of samples for laboratory analysis since it was felt that sufficient data had already been collected in previous years to define the raw wastewater characteristics. The overflow duration generally ranged between 30 and 140 minutes for any one storm. A summary of the overflow occurrence data is shown in Table 19. The interval between successive overflows ranged widely from 0.5 days to 34 days. No specific relationship could be established between the amount of particulate matter in the CSO (as shown by the suspended solids) and the period between successive overflows. Data on rainfall was obtained routinely and is shown for most storms in Table 19. The rainfall data on a few storms was missed because of minor maintenance problems with the raingauge. No attempt was made to measure the rate of flow in the sewer because of the following two reasons as pointed out in an earlier report on screening/flotation treatment (70):

1. It is difficult to measure the flow in the Hawley Road sewer under prevailing conditions as described previously on page 51.
2. Such measurement does not influence the operation of the demonstration system.

A summary of the characteristics of the combined sewer overflow quality is presented in Table 20. The data is included not only for the 1971 operational season but also has been compared with the past two years of data. All data is presented at 95% confidence level. The pollutant levels for this year generally fall in between the first flush and the extended overflow pollutant levels recorded during the two previous years. This is expected since the first flushes and the extended overflows were not separated out for the 1971 season. The detailed analyses and the operational parameters for each over-

Table 19. SUMMARY OF OVERFLOW OCCURRENCE DATA - 1971

Overflow no.	Days between overflows	Duration of overflow, min.	Suspended solids, mg/1	Average rainfall intensity, in/hr.
71-1	--	30	172	0.50
71-2	8	59	206	0.60
71-3	9	30	1,025	1.00
71-4	1	32	322	0.35
71-5	6	107	560	2.00
71-6	1	57	437	0.90
71-7	1	143	78	0.25
71-8	2	64	556	1.40
71-9	16	70	330	0.36
71-10	11	50	886	0.10
71-11	14	85	313	0.12
71-12	8	57	188	0.75
71-13	4	46	229	1.10
71-14	0.5	83	138	0.65
71-15	6	35	303	0.04
71-16	2	37	580	3.70
71-17	34	55	1,074	0.09
71-18	2	49	336	0.09
71-19	6	95	349	0.14
71-20	16	54	293	0.67
71-21	13	120	204	0.10

Note: Average rainfall intensities for overflows Nos. 71-9, 71-10, 71-11, 71-15, 71-17, 71-18, 71-19, and 71-21 estimated from data obtained from local weather burea.

Table 20. SUMMARY OF RAW WATER QUALITY DATA - (1969-1970)

	Constituent concentration at 95% confidence level		
Analysis	1971 Season[a]	1969-70 First flushes[b]	1969-70 Extended overflows[c]
pH	7.2 ± 0.1	7.0 ± 0.1	7.2 ± 0.1
Total solids, mg/l	605 ± 151	861 + 117	378 ± 46
Total volatile solids, mg/l	156 ± 73	489 ± 83	185 ± 23
Suspended solids, mg/l	435 ± 129	522 ± 150	166 ± 26
Vol. suspended solids, mg/l	146 ± 46	308 ± 83	90 ± 14
TOC, mg/l	73 ± 27	---	---
COD, mg/l	209 ± 86	581 ± 92	161 ± 19
BOD, mg/l	64 ± 32	186 ± 40	49 ± 10
Dissolved TOC/Total TOC	0.36 ± 0.05	---	---
Dissolved COD/Total COD	--	--	0.34 ± 0.04
Total Nitrogen, mg/l	6.3 ± 1.9	17.6 ± 3.1	5.5 ± 0.8
Ortho Phosphate, mg/l	0.86 ± 0.37	2.7 ± 1.0	1.0 ± 0.24
Coliform density per ml	75.5 ± 69 x 10^3	142 ± 108 x 10^3	62.5 ± 27 x 10^3

a. Data represents 21 overflows
b. Data represents 12 overflows
c. Data represents 44 overflows

flow are included in Appendix E (Tables E-41 and E-42). It can be seen that there is a wide variation in the waste water quality. The particulate matter concentration measured as suspended solids varied between 78 and 1074 mg/l. The dissolved solids content of the CSO is again quite low. The TDS (Total dissolved solids) based on the difference of total solids and suspended solids of Table 20, is 170 mg/l. This value is very similar to the TDS content of the Milwaukee tap water and represents a very insignificant change.

Of particular interest to this project are the volatile and the dissolved organic fractions in the combined sewer overflows. Table 21 presents data on these relationships for 1969-1971 operational seasons.

The dissolved COD or TOC fraction is in close agreement for the three year data and ranges between 30 to 41% of the total COD or TOC. The dissolved organic material will not be removed by the screening process and will influence the removal efficiencies of COD and TOC. The volatile fraction in the particulate matter has been found to be significantly lower for the 1971 season. It can be seen from Table 21 that the VSS/SS fraction for this year is only 25% as compared to 57% for the two previous seasons. Thin layers of fine cementous material were observed on the inside walls of the screening chambers at the end of overflow runs. These may have been a result of the washings from the new lining of the sewers in the drainage area during the spring of 1971. The resultant effect of this fine cementous material would be to decrease the volatile fraction of the particulate matter. This fine material will not be removed on the drum screens and will again tend to lower the removal efficiencies.

OPERATION OF THE SEQUENTIAL SCREENING SYSTEM (FIELD TESTS)

The sequential screening system was operated on a total of 21 overflows. A summary of the operating conditions for the three screens is presented in Table 22. A detailed listing of complete data is included in Appendix E, Tables E-41 to E-46. The feed flow rates to the screening system varied between 1800 and 3300 gpm. The resulting hydraulic loadings ranged between 15 and 43 gpm/sq ft based on the maximum wetted surface areas of the screens. The drum rotation speeds varied in the range of 1 to 7 rpm. Of the 21 overflows monitored on the screening system, 15 were operated without any flocculating chemicals while a cationic polyelectrolyte (Nalco 607) was added to the remaining 6 overflows. Chlorine was added to 13 of the overflows for disinfecting the waste waters. The chlorine dosages ranged between 5 and 17 mg/l.

The summaries of the pollutant removal efficiencies across the screening system (1 to 3 screens in series) are tabulated in Tables 23 and 24. These removals are presented as percentage removals because of the wide range of pollutional values obtained in the raw waste. Absolute effluent water quality data may be seen in Appendix E, Tables E-43, E-44, and E-45. The absolute values can also be estimated by applying the observed percentage removal numbers (Tables 22 and 23) to the raw overflow water quality presented in Table 20.

Table 21. DISSOLVED ORGANIC AND VOLATILE FRACTIONS IN COMBINED SEWER OVERFLOWS

Relationship	No. of samples	95% confidence level	
		1969-70 season	1971 season
Dissolved COD/total COD	34	0.34 ± 0.04	---
Dissolved TOC/total TOC	21	---	0.36 ± 0.05
Volatile suspended solids/suspended solids	56[a], 21[b]	0.57 ± 0.04	0.35 ± 0.06

a. No. of samples for 1969-70 data
b. No. of samples for 1971 data

Table 22. OPERATING CONDITIONS FOR THE SERIES SCREENING SYSTEM

Run #	Feed flow, gpm	Hydraulic loading[a] gpm/sq ft Screen 1	Screen 2	Screen 3	Length of run, min	Drum speed, rpm Screen 1	Screen 2	Screen 3
71-01	3300	43.4	26.8	26.8	30	6.5	6.9	5.0
71-02	3295	43.25	26.7	26.7	59	5.8	5.3	5.2
71-03	3273	43.1	26.6	26.6	30	5.8	5.3	5.2
71-04	3225	42.5	26.25	26.25	31.8	4.4-7.6	5.3	5.2
71-05[b]	3240	42.6	26.35	26.35	106.5	4.4	5.3	5.2
71-06[b]	3270	43.0	26.6	26.6	56.7	4.4	5.3	5.2
71-07[b]	3300	43.4	26.8	26.8	143	4.4	5.3	5.2
71-08	3280	43.2	26.65	26.65	64	4.4	3.5-4.6	3.4-4.9
71-09[b,c]	3540	46.6	28.8	28.8	70	4.45	4.6	4.85
71-10	3100	40.8	25.2	25.2	50	4.45-6.7	4.6	4.85
71-11[b]	2740	36.1	22.3	22.3	85	6.7-2.05	4.6-1.5	4.85-1.9
71-12[b]	1850	24.3	15.0	15.0	47	2.05	1.5	1.4
71-13[b]	1795	23.6	14.6	14.6	46	2.05	1.5	1.4
71-14[b]	1835	24.1	14.9	14.9	82.6	2.05	1.5	1.4-2.55
71-15[b]	1870	24.6	15.2	15.2	35	5.8	4.0	4.4
71-16[b]	1870	24.6	15.2	15.2	37	5.8	4.0	4.4
71-17[c]	2100	27.6	17.1	17.1	55	5.8	4.0	3.85
71-18[c]	2300	30.2	18.7	18.7	49	5.8	4.0	3.85
71-19[b,c]	2300	30.2	18.7	18.7	95	5.8	4.0	4.4
71-20[b,c]	2210	29.1	18.0	18.0	54.4	5.8	4.0	4.4
71-21[b,c]	2360	31.1	19.2	19.2	120.2	5.8	4.0	4.4

[a] Wetted area at maximum headloss
Screen 1: 76 sq ft
Screen 2 & 3: 123 sq ft

[b] Added 5-17 mg/l of chlorine to these overflows

[c] Added 5 mg/l of Nalco 607 (cationic polyelectrolyte) to these overflows

Note: Screen opening microns (μ)
Screen 1: 841 (20 mesh)
Screen 2: 149 (100 mesh)
Screen 3: 63 (230 mesh)

Table 23. SUMMARY OF OVERALL POLLUTANT REMOVALS ACROSS THE SCREENING SYSTEM[a]

Analysis	Percent removals at 95% confidence level	
	Without chemical flocculants[b]	With chemical flocculants[c]
Suspended solids	28 ± 8	22 ± 14
Volatile suspended solids	32 ± 11	31 ± 17
TOC	25 ± 12	12 ± 17
COD	30 ± 9	10 ± 7
BOD	28 ± 7	16 ± 15

a. Three screens in series 841m, 149μ, 63μ
b. Represents 15 runs
c. Represents 6 runs with cationic polyelectrolyte Nalco 607

Table 24. SUMMARY OF POLLUTANT REMOVALS ON VARIOUS SCREENS BASED ON RAW INFLUENT QUALITY

Analysis	Percent removals at 95% confidence level		
	A. Runs without chemical flocculants[a]		
	Screen 1	Screens 1 & 2	Screens 1, 2 & 3
Suspended solids	8 ± 13	22 ± 8	28 ± 8
Volatile suspended solids	15 ± 19	21 ± 14	32 ± 11
TOC	7 ± 16	15 ± 14	25 ± 12
COD	6 ± 10	17 ± 13	30 ± 9
BOD	20 ± 13	17 ± 13	28 ± 7
	B. Runs with chemical flocculants[b]		
Suspended solids	14 ± 15	16 ± 8	22 ± 14
Volatile suspended solids	4 ± 48	24 ± 12	31 ± 17
TOC	3 ± 10	4 ± 14	12 ± 17
COD	3 ± 8	2 ± 19	10 ± 7
BOD	10 ± 12	17 ± 28	16 ± 15

a. Represents 15 runs
b. Represents 6 runs with cationic polyelectrolyte Nalco 607

Note: Screen 1: 841 μ; Screen 2: 149 μ; Screen 3: 63 μ

Generally, the overall percent removals across the screening system was in the range of 30% without the addition of any chemical flocculants. The percent removals were lower for the runs with chemical flocculants. The reason for such a decrease in the removal efficiencies are not known. However, a good comparison cannot be made as only six runs were made with chemical flocculant addition and the range of removals was quite large. Table 24 presents a summary of the progressive removals through the screening system in various stages. The percent removals on the coarse drum screen (841μ) were extremely low because of the relatively large openings. The removals on the coarse and medium screens in series were only slightly (~15%) improved. The improvement in pollutant removals was of the order of 5% only when all the three screens were in series. Since the success of a mechanical separation process such as screening is dependent largely upon the particle size distribution in the raw waste, it was indicated that the poor performance of the screening system may have been a result of the particle size distribution in the combined sewer overflows. This necessitated the need to develop information regarding the particle size distribution of CSO in order to improve the pollutant removal efficiencies via the screening process.

In an effort to improve upon the efficiency of the screening system, several measures were undertaken during the operation of various runs. Specific measures that were tried were:

1. Reductions in hydraulic loadings and solids loadings by changing the raw flow rate and drum speeds.
2. Thorough inspection of the sampler system, the drum screen panels and other mechanical and electrical components and controls that could affect the performance of the system.
3. Bench scale tests to provide detailed information on screening removal efficiencies as well as comparison with the field data.
4. Addition of chemical flocculants in the field as well as bench scale evaluation of promising chemical flocculants that will provide a quick floc to be removed on the screens.

The variation in the feed flow rates and the drum rotation speeds for all the 21 overflows is presented in Table 22. The resultant hydraulic and solid loadings are shown in Table 25. The hydraulic loading varied between 15 to 45 gpm/sq ft. The solids loadings, calculated for the entire duration of the overflow were generally less than the design solids loading of 1.4 lbs/100 sq ft. However, the solids loadings exceeded the design values many times during the initial stages of several overflows. This is expected because of the variation in the raw water quality over the duration of an overflow. No significant increase in removal efficiencies was attained due to the change in the hydraulic and solids loadings.

During the initial phase of the screening operation; it was thought that the poor performance of the screening system might have been a cause of some mechanical operational problem such as leaks, sampling system and other minor maintenance problems. A thorough inspection of the screen panels, sampler

Table 25. VARIATION IN HYDRAULIC & SOLID LOADINGS ON THE SCREENS

Run no.	Hydraulic loadings[a], gpm/sq ft			Solids loadings[b] based upon influent and effluent quality on individual screens, lbs/100 sq ft		
	Screen 1	Screen 2	Screen 3	Screen 1	Screen 2	Screen 3
71-01	43.4	26.8	26.8	--	--	0.33
71-02	43.25	26.7	26.7	--	0.33	0.33
71-03	43.1	26.6	26.6	--	--	0.63
71-04	42.5	26.25	26.25	--	0.54	<0.01
71-05	42.6	26.35	26.35	0.04	0.20	0.39
71-06	43.0	26.6	26.6	0.15	0.09	0.08
71-07	43.4	26.8	26.8	0.07	<0.01	--
71-08	43.2	26.65	26.65	1.05	0.08 - 0.11	--
71-09	46.6	28.8	28.8	--	0.45	--
71-10	40.8	25.2	25.2	1.3-1.9	0.28	--
71-11	36.1	22.3	22.3	0.2-0.6	0.01-0.03	--
71-12	24.3	150.	150.	0.21	0.04	0.14
71-13	23.6	14.6	14.6	0.27	0.17	--
71-14	24.1	14.9	14.9	<0.01	0.04	0.16-0.30
71-15	24.6	15.2	15.2	0.12	0.02	--
71-16	24.6	15.2	15.2	0.14	--	--
71-17	37.6	17.1	17.1	0.25	--	0.49
71-18	30.2	18.7	18.7	0.21	0.05	0.05
71-19	30.2	18.7	18.7	0.32	--	0.27
71-20	29.1	18.0	18.0	0.15	0.04	--
71-21	31.1	19.2	19.2	0.18	--	0.09

a. Wetted screen area at maximum headloss
Screen 1: 76 sq ft
Screens 2 & 3: 123 sq ft

Note: Screen opening, microns
Screen 1: 841 (20 mesh)
Screen 2: 149 (100 mesh)
Screen 3: 63 (230 mesh)

b. Solids loadings based upon entire duration of overflow. Maximum available screen area per revoluation Screen 1: 101.5 sq ft; Screens 2 & 3: 164 sq ft location and operational controls was made to eliminate any possibly problem areas. However, no significant areas of concern were found although some modifications in the sampler system and its locations were made to insure collection of truly representative samples.

A chemical flocculant Dow C-31 was added in runs 71-09 and Nalco 607 was added in runs 71-17 through 71-21 at a dosage of 5 mg/l. Both the above polymers are cationic in nature. Dow C-31 had earlier been used at the Hawley Road facility for screening/flotation treatment (70). The polyelectrolyte Nalco 607 was selected based on initial bench scale studies with various polymers. The polymers were added in the raw waste for runf 71-09, 71-17, 71-18 and 71-19 and in the effluent from screens #2 for runs 71-20 and 71-21. Addition of these polymers at the two separate locations did not provide any improvement in the removal efficiencies (Table 24) of the screening system. However, it should be noted that a specific flocculation period was not provided and effective flocculation may not have occurred. Additional qualitative bench scale tests on raw combined sewer overflow samples from runs 71-19 and 71-20 indicated two promising flocculants in Magnifloc 905-N (non-ionic) and Atlas 105C (cationic). Both these polymers can provide an excellent floc. Unfortunately, field testing of these flocculants could not be possible due to the shutdown of the treatment facility with the onset of cold weather. However, it is recommended that these promising chemical flocculants be evaluated in future field screening tests and consideration be given to the provision of proper flocculation period prior to screening.

BENCH SCALE SCREENING TESTS

In an effort to obtain more detailed information on the removal efficiency utilizing screens with various size openings, a series of bench scale tests were performed. Results of the wet sieve analysis performed on the raw overflow from Storm No. 71-12 are shown in Table 26.

Table 26. WET SIEVE ANALYSIS RESULTS ON
STORM 71-12 RAW OVERFLOW

Screen opening	Weight retained, gms	% retained, by weight
20 mesh (841μ)	0.0151	2.0
100 mesh (149μ)	0.0193	2.6
200 mesh (84μ)	0.0071	1.0
400 mesh (37μ)	0.0322	4.3
Filtrate from 400 mesh	0.6680	90.1

It can be seen from this table that only a total of 10% of the particulate matter by weight was retained on various screens up to 400 mesh (37 microns). This indicates that 90% of the particulate matter by weight was finer than 37 microns for this particular overflow event. Side-by-side data with field testing was obtained on storms 71-15, 71-16 and 71-20. A comparison of this data is presented in Table 27.

Removals of volatile suspended solids and TOC generally agreed, however, suspended solids removals were all significantly higher in the laboratory tests as compared to the full scale systems. It is not known what was causing this difference, but it may have been the sampling techniques or the inherent differences between the bench scale and the full scale systems. In any event, additional side-by-side bench scale testing is recommended for future field screening tests. This will allow proper scale up factors to be determined and the reliable bench scale testing technique to be developed.

In an effort to improve upon the screening efficiency, finer micronic screens [finer than 230 mesh (63μ)] were utilized in bench scale tests. A comparison of the screening efficiencies of the 63 micron square weave screen with the 23 micron twill weave screen is shown in Table 28. Both these screens were in stainless steel media. It can be seen from this table that the pollutant removal efficiencies for 63 micron screen were in the range of 20 to 40% while the corresponding removal efficiencies were in the range of 55 to 90% for 23 micron screen. An exception in the removal efficiencies is evident for run no. 71-20 where the highest suspended solids removal was only 37% and the volatile suspended solids and TOC removals were extremely poor. This observation shows the high degree of variability that can be generally expected in the particle size distribution in combined sewer overflows. However, in most overflows greater than 50% of the particulate matter was found to be in a particle size range of 20 to 60 microns. Figure 29 presents a plot of suspended solids removal against screen size opening. It may be seen in this figure that a significant increase in removal efficiency was obtained at screen openings of 18 to 23 microns. Since the success of a mechanical separation process such as screening is dependent to a great extent upon the particle size distribution in the raw waste, it appears that decreasing the size of opening on the third drum the series screening system will provide a significant increase in the removal efficiencies. It is also apparent from the full scale and bench scale data that three screens in series hold no advantage over a single screen. It may be necessary, however, to use a roughing screen to protect the very fine mesh (small opening) screens required for high removal of contaminants from combined sewer overflows.

Most of the screening media utilized during the bench scale and field tests was made of stainless steel. However, a wide variety of plastic media screens made in nylon and polyester are available now at $4/sq ft. Plastic media screens are significantly cheaper (approximately by a factor of 5-8) than the stainless steel media screens in comparable screen openings. Moreover, the square weave stainless steel media is very susceptible to damage because of the thin wire size utilized in its weaving. Plastic media screens are comparably stronger in square weave. Samples of the plastic media screens were not received in time to evaluate their application feasibility on the Hawley

Table 27. COMPARISON OF BENCH SCALE AND FULL SCALE SCREENING DATA

	Raw waste, mg/l					% Removals on 63μ screen[a]			
				Suspended solids		Volatile suspended solids		TOC	
Run no.	Suspended solids	Volatile suspended solids	TOC	BS	FS	BS	FS	BS	FS
71-15	303	181	112	32	10	29	21	21	24
71-16	579	112	69	46	12	27	23	59	26
71-20	293	112	82	19	10	--	--	--	--

a. BS : Bench scale test
FS : Full scale test

Table 28. COMPARISON OF POLLUTANT REMOVAL EFFICIENCIES OF 23 AND 63 MICRON SCREENS

Run no.	Suspended solids	Volatile suspended solids	TOC	Percent pollutant removals					
				Suspended solids		Volatile suspended solids		TOC	
				63μ	23μ	63μ	23μ	63μ	23μ
71-15	303	181	112	32.4	88.4	28.6	80.7	20.5	58.0
71-16	579	112	69	43.6	93.6	26.8	76.8	59.4	82.7
71-5 (DAF)	350	127	73	31.4	69.2	27.5	52.8	23.3	64.4
71-19	349	126	36	31.7	65.0	---	---	---	---
71-20	293	112	82	19.0	37.0	0	4.5	0	11.5
Racine CSO sample	48	31	28	25.0	54.5	22.5	54.8	21.4	64.0

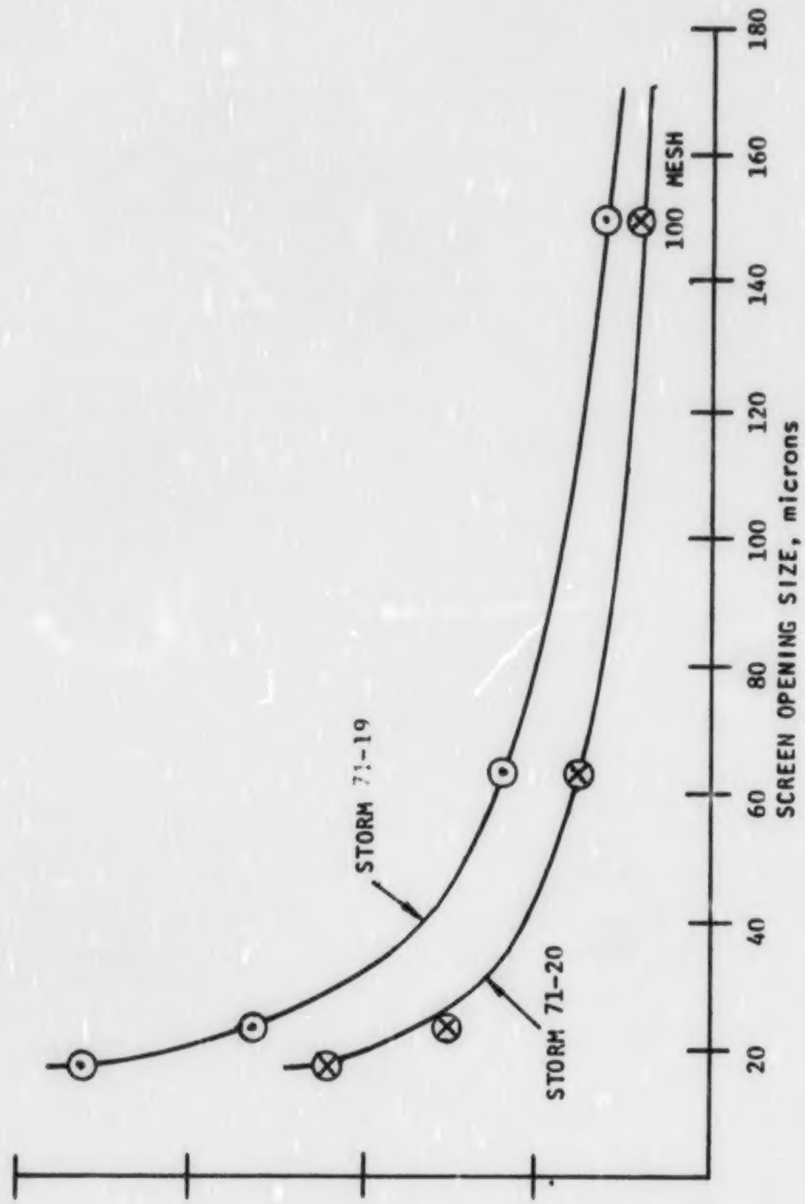


Figure 29. Bench scale screening data

Road CSO. It is therefore recommended that these screens be evaluated before making a final selection of the micronic screen for the treatment of combined sewer overflows.

OPERATION OF THE BACKWASH SYSTEM

The screens were backwashed with waters from respective screened effluent chambers via separate pressurizing pumps. Spray nozzles with 1/4" diameter orifices were used to effectively distribute the water over the screen media. Washing was performed from outside the screen drums. The total screen water utilized varied between 100-130 gpm. With the installation of 1/16" strainers on the backwashing waters, almost no nozzle plugging problems were experienced. However, it was felt that the amount of screen water volume can be further reduced by placing the spray nozzles closer to the drum screens. Currently the spray headers are approximately 12" from the drum screens. It is felt that a distance of 4 to 6" should provide sufficient spray backwashing at 30-50 gpm. At this rate, the spray wash requirements would amount to only 1 to 2% of the raw waste flow when continuous washing of the screens is provided. The actual spray wash utilized with intermittent washings (only when screens were blinded) were in the range of 0.5 to 2% of the raw flow. Screen wash quality ranged between 500 to 9,000 mg/l suspended solids. A listing of the screen wash volumes and quality data is presented in Appendix E, Tables E-41 and E-46.

DISINFECTION OF COMBINED SEWER OVERFLOWS

A summary of the disinfection data utilizing chlorine is presented in Table 29. A total of 13 overflows were treated with chlorine. Calcium hypochlorite was utilized as a source of chlorine. The range of chlorine dosages used was 5 to 17 mg/l. It was found that the sequential screening system provided adequate detention time (∿5-10 minutes) for effective disinfection when chlorine was introduced in the raw overflow. Based on the results shown in Table 29, a dosage of 7.5 to 10 mg/l was considered sufficient for effective disinfection. Results of only one overflow (No. 71-12) were significantly poorer where a high number of coliforms was recorded in the screened effluent in spite of the use of a chlorine dose of 10.3 mg/l. The reason for this poor disinfection may have been due to some error in the handling of the effluent sample. Nevertheless it was concluded that good disinfection can be obtained in conjunction with the operation of a sequential screening system.

Table 29. SUMMARY OF DISINFECTION DATA WITH CHLORINE

Storm no.	Chlorine dosage, mg/l	Total coliforms, no./ml Influent	Total coliforms, no./ml Effluent
71-5	7.5	31,000	54
71-6	7.5	115,000	<1
71-7	7.5	6,000	<1
71-9	7.5	490	0
71-11	5.0	3,600	<50
71-12	10.3	6,500	2,178
71-13	11.0	34,000	6
71-14	11.0	140	3
71-15	15.0	380,000	3
71-16	17.0	128,000	2
71-19	9.0	5,700	<1
71-20	6.7	9,000	100
71-21	10.0	21,000	<1

SECTION X

INVESTIGATIONS CONDUCTED FOR UPGRADING SCREENING/FLOTATION PERFORMANCE

Previous work performed and described in preceding sections of this report has shown that:

1. Screening/flotation is an effective method for reducing pollution caused by combined sewer overflows. The overall pollutant removals achieved, measured in terms of suspended solids, volatile suspended solids, BOD and COD, ranged between 60% and 75%.

2. Sequential screening was not as effective as screening/flotation in reducing pollution caused by combined sewer overflows. The percentage removals attained by sequential screening were about 30% for the contaminant parameters of suspended solids, volatile suspended solids, BOD, COD and TOC. It was concluded that the use of three screens in series did not show any advantage over the use of a single screen.

Bench scale investigations were then investigated in an effort to improve the observed pollutant removal efficiencies. For example,

1. Bench scale investigations showed that a significant increase in pollutant removal efficiencies could be obtained by using screening material which had openings of 18 to 23 microns.

2. Also, laboratory bench scale tests using various dissolved-air flotation treatment modes indicated that the quality of the treated effluent in the effluent recycle mode of operation was significantly better than that using the split flow mode of operation.

3. Moreover, bench scale tests demonstrated that powdered activated carbon, when used in conjunction with dissolved air flotation in the effluent recycle mode, provided excellent removals of both particulate and soluble organic pollutants.

The bench scale investigations alluded to in Item No. 1, above, were performed and described as a part of the work reported previously in Section IX.

The laboratory studies referred to above in Item Nos. 2 and 3 were performed separately as part of a larger study conducted to compare and evaluate the feasibility of various means for upgrading flotation treated combined sewer overflows. A detailed account of these feasibility studies is documented in

Appendix B.

Based on the bench scale findings described above, additional work was performed at the Hawley Road site utilizing the 5 mgd demonstration systems to evaluate the following modifications and additions on the upgrading of screening/flotation performance.

1. Screening/flotation system operation after conversion of flotation system to effluent pressurization.
2. Conversion of the third drum screen on the sequential screening system to accommodate a 18-23 micron opening synthetic media screen and the operation of the screening system on both the flotation effluents and raw CSO's.
3. Conducting separate field tests using powdered activated carbon and coagulants with the screening/flotation system as modified under item 1, above.

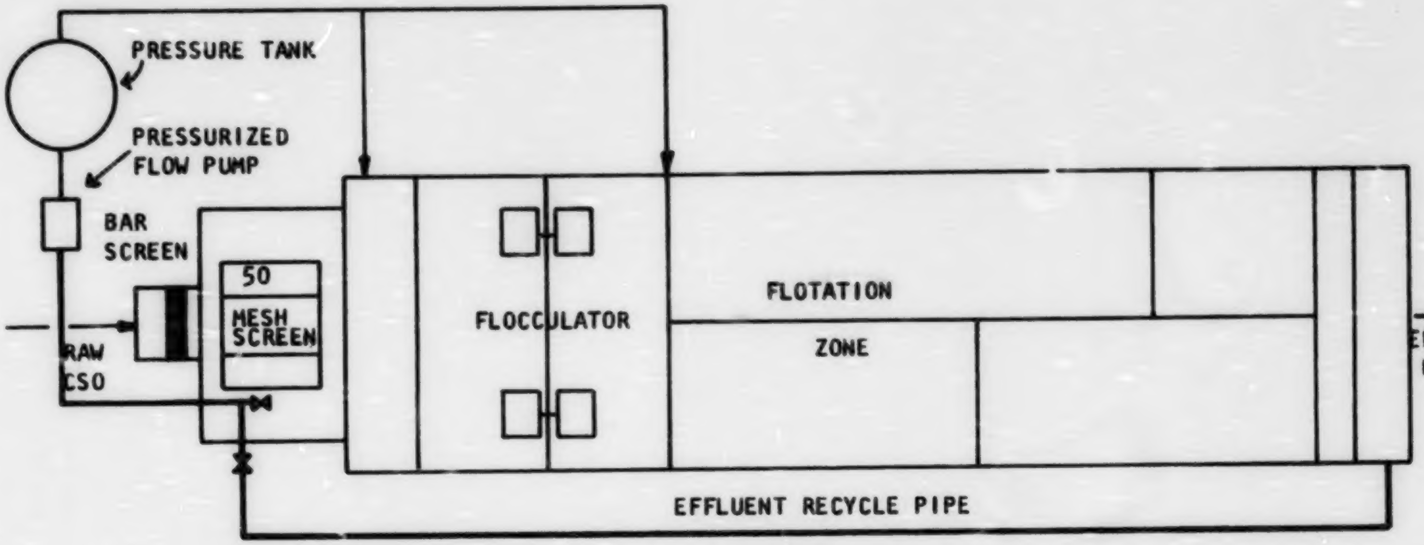
The following discussion summarizes and documents the work performed in the upgrading investigation.

SCREENING/FLOTATION USING EFFLUENT PRESSURIZATION AND MICROSCREENING OF FLOTATION EFFLUENT

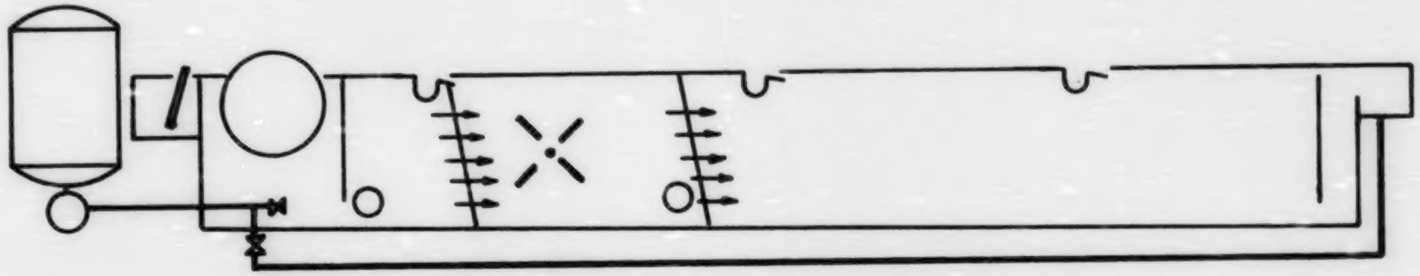
The original system design at Hawley Road utilized screened, raw wastewater as the source of liquid stream for pressurization. The advantage of this initial approach was to decrease the hydraulic loading on the DAF tank and thereby reduce the tank surface area requirements. The bench scale tests performed indicated that the use of the treated effluent as the pressurized flow source enhanced suspended solids removals. To utilize DAF effluent as the liquid stream source for pressurization, an 8 inch pipe was installed along the outside of the flotation tank from the effluent trough to the existing liquid stream manifold inside the screened water tank. A schematic representation of these modifications is shown in Figure 30. A slope of 1/8 inches per foot permitted gravity flow of the effluent to the header manifold. Appropriate valves at this juncture permitted the choice of either screened water or DAF effluent as the liquid stream source for pressurization.

The second modification for upgrading the effluent quality from the DAF unit involved the microscreening of the flotation effluent. No modifications were required to transfer the DAF effluent to the screening system as the necessary equipment was already installed. The modifications necessary to the screening system are discussed below.

The original treatment process consisted of passing the waste flow sequentially through a series of screens of varying size openings. A representation is shown in Figure 31. A raw feed pump delivered the waste stream from a sump in the sewer to the screening system. The raw waste passed through a 1/2 inch bar rack, to remove large objects which may clog or damage the finer mesh



PLAN



ELEVATION

Figure 30. Modifications to dissolved-air flotation system

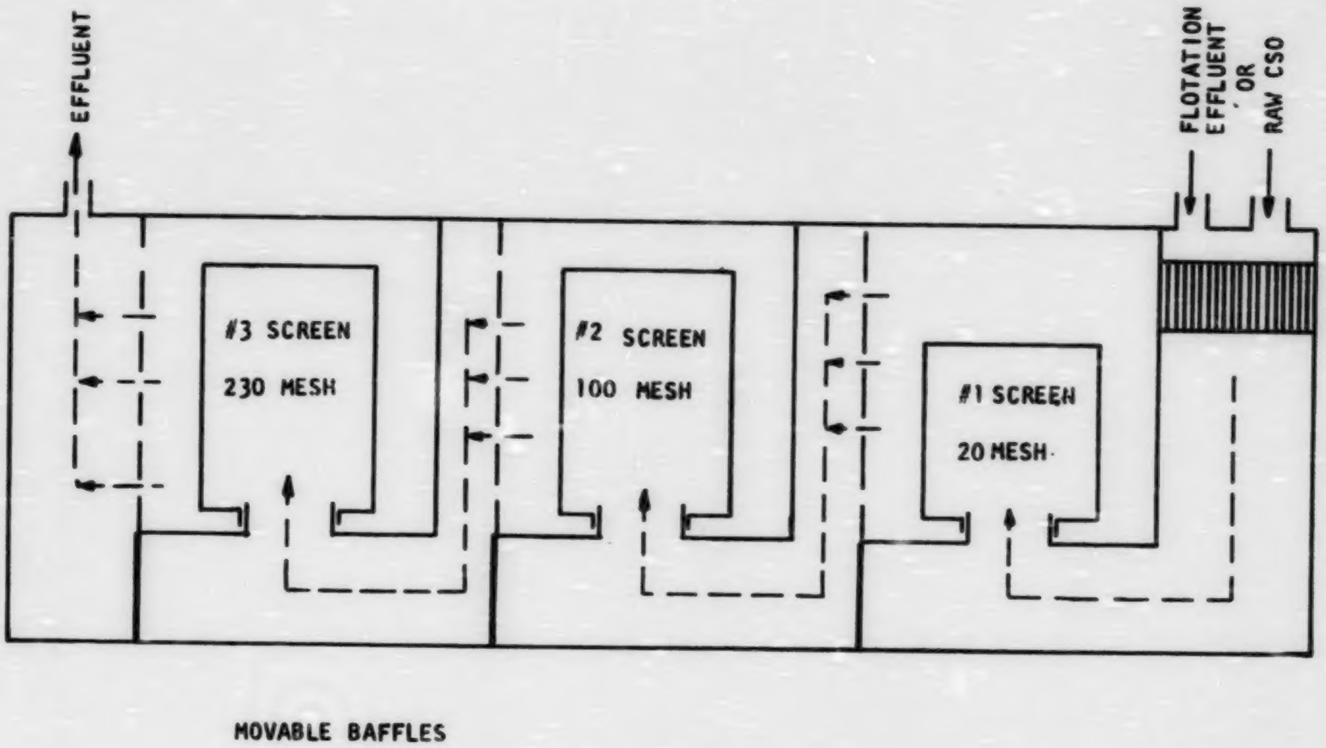


Figure 31. Schematic flow diagram for sequential screening system

drum screens. The flow was then channeled through a series of three drum screens. The drum screens were contained in basins of steel construction and were cleaned with spray backwash nozzles. The water utilized for the spray backwashing was the screened effluent from the respective drum basins. The captured solids from each screen were discharged to a sanitary sewer located at the site. The treated effluent was discharged to the Menomonee River. A transfer pump and a pneumatic flow rate controller was also provided to transfer flotation treated effluent to the sequential screening system. In addition, the influent channel walls between adjacent drum screens could be removed to provide maximum flexibility in operational modes.

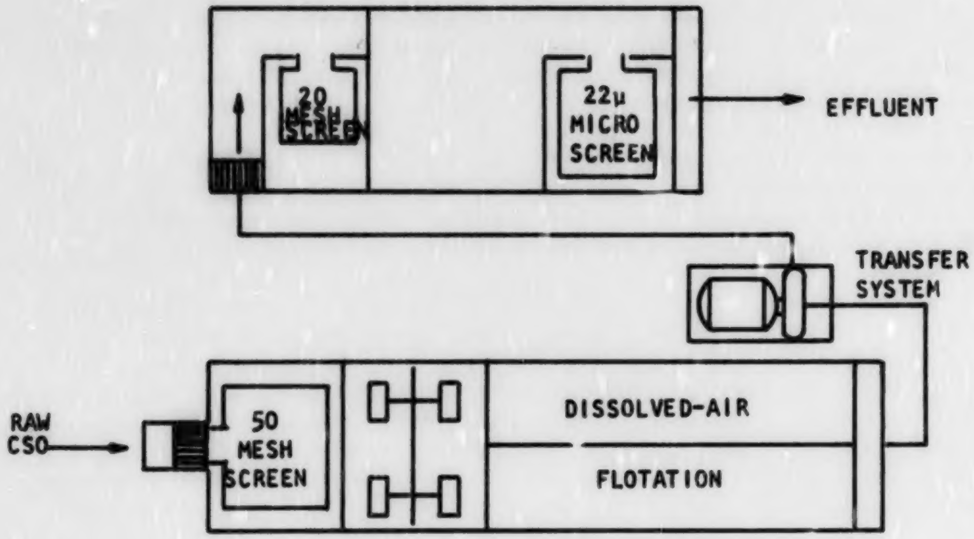
The stainless steel screens originally used ranged from 20 mesh (841 microns) to 230 mesh (63 microns). As a result of the laboratory bench scale testing with various fine screen medias, a nylon media was selected for the microscreening tests. The selected screen was a 343 x 66 mesh, plain reverse dutch weave type media and had nominal pore openings of 22 microns. The media, designated NY-76-k, was supplied by the TET-KRESSILK Co. This media was supported by and retained on 18 x 24 inch high density polyethylene grid panels. These panels, in turn, were clamped onto the screen drum by mild steel retaining bars. Additional cross braces were added to support the panels' end points. A total of 54 grid panels were used to cover the third drum screen. The total exposed microscreen area was 98.5 sq ft. No further alteration was needed except for the removal of the old screening media, the additional cross braces, and the grinding of a few rough weld burrs, to adapt the drum to accept the microscreen media. The backwash spray header was lowered to provide better spray penetration through the finer mesh screen.

Initial sequential screening results had shown no appreciable advantage in passing the process stream through progressively finer screens, however, the coarse, 20 mesh screen was retained in the process scheme to protect the delicate nature of the microscreen cloth. The influent channel baffle in the second screen chamber was removed allowing the waste stream to bypass that chamber and flow directly from the roughing screen (20 mesh) to the microscreen drum.

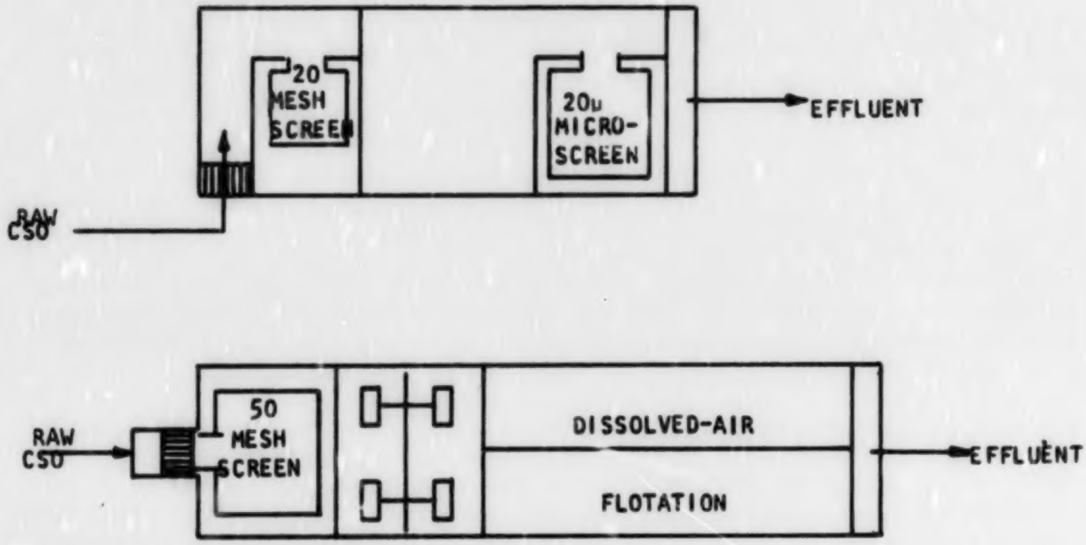
While existing metering and recording equipment provided influent and backwash flow rates and volumes, a differential pressure recording meter was installed to measure the inches of water headloss across the microscreen.

The process versatility of the two systems is apparent. Each system had the capability of independent operation, that is, separate raw pump controls, metering and measuring devices. In addition, a transfer pump system allowed the effluent from either system to be transferred to the inlet of the other treatment system. A process sheet illustrating these flow schemes is shown in Figure 32.

The modification of the existing split flow flotation system to one with effluent pressurization and the conversion of the third drum of the series screening system to a microscreen (22 micron opening) was completed in the early summer of 1973. Both systems were then put into automatic startup operation. The two systems were initially run in series to evaluate both the performance of effluent pressurization and of the microscreen polishing of



OPERATION OF THE TREATMENT SYSTEMS IN SERIES



OPERATION OF THE TREATMENT SYSTEM IN PARALLEL

Figure 32. Dissolved-air flotation & microscreening operation modes

flotation effluent. The parameters associated with this mode of operation included overflow rates, chemical dosages, percent recycle rates and effluent quality. Midway into the operation season, the micro screening testing was extended to include direct screening of raw CSO, and the results of this testing will be reported later in this section. The flotation unit was then operated parallel to the screening system to provide a comparison of process methods while also accumulating more data on the effect of effluent pressurization on effluent quality. A brief description of the operating methods of each of the treatment systems follows.

The flotation system was put into operation automatically when a pressure switch in the sewer sensed an overflow. The pressurized flow system was then immediately put into operation and the raw feed pump began to prime. All runs were started with the tank full of water from the previous run. The raw pump generally primed in about 7-12 minutes. When primed, the raw pump was activated, and the flow meters, chemical feeder, skimmers and all other auxiliary equipment were put into operation. The transfer pump and a pneumatic flow rate controller automatically transferred the flotation treated effluent to the screening system. At the end of the run, the system shut down automatically. Process variables were then selected for the next run and the controls positioned accordingly. Variables associated with the tank operation included the pressurized flow rates, injection air pressure, overflow rates, and chemical dosages.

Although the microscreening system had automatic startup capabilities, it was put into operation manually in order to observe and control any excessive headlosses across the screens that might occur. By switching the transfer pump and pneumatic flow controller to an automatic mode, the drum screens, sampling system, flow meters and the backwash system (operated only when headloss across the screen reached a preset level) were put into operation. At the end of the overflow, the system shut down automatically. When treating raw CSO, the system was manually switched to the automatic mode whereby the drum screens were immediately put into operation and the raw feed pump began to prime (generally in about 7 to 10 minutes). On priming, the raw pump and the above mentioned support systems were all activated. At the end of the overflow, the system shut down automatically. The controls were then positioned for regulating the desired variables for the next run. The variables associated with the screening operation included raw flow rate, drum screen speeds, backwashing rates and headloss across the screens.

The flotation system sampling began automatically when the raw pump primed. Raw waste and screened water sample collection was started immediately. Effluent sample collection was delayed for one tank detention period to allow purging of the water in the tank from the previous run. This procedure insured collection of representative effluent samples. Screen backwash and floated scum samples were taken during screen backwash and scum removal periods.

The automatic sampling system consisted of two timers connected through the proper valving, to automatically composite the raw waste, screen water and effluent samples. The first timer controlled the sample taking frequency (0-30 minutes). The second timer controlled the duration of sampling time (0-60 seconds). The sampling valves were air operated weir valves. In general, samples were composited every 5 minutes with the automatic system. Floated scum and screen backwash sample taking was not automated due to the problems associated with intermittent flows and heavy solids concentrations in these process streams. The samples were refrigerated immediately after the run. Analyses were then started within 0-8 hours.

The screening system was automatically sampled in a similar manner. Generally, the samples were composited every five minutes with the automatic system throughout the duration of the overflow. The first samples of the raw and the screened effluent were collected after a minimum of 5 minutes of system operation had elapsed to allow purging of any waste remaining from previous tests. After collection, the samples were handled as described above.

To define the removal efficiencies of each process, it was proposed to run the same schedule of analytical tests as described in Sections VII and IX with the following exceptions.

1. Total and dissolved TOC in place of COD analysis.
2. Effluents from the coarse screen (50 mesh) to be analyzed only for suspended solids, volatile suspended solids and TOC.
3. Total phosphorus in place of ortho phosphates.

A listing of the analysis schedule is presented below.

ANALYSIS SCHEDULE

Analysis	Raw waste	Coarse screen	Fine screen	Flotation effluent	Screen backwash	Flotation sludges
pH	x	x	x	x	x	x
Total solids	x		x	x	x	x
Total volatile solids	x		x	x	x	x
Suspended solids	x	x	x	x		
Total organic carbon	x	x	x	x		
Dissolved organic carbon	x	x	x	x		
BOD	x		x	x		
Total organic nitrogen	x		x	x		
Total phosphorus	x		x	x		
Total coliform	x		x	x		

Sample analysis procedures are discussed in Appendix C.

Test Plan

The variables associated with the operation of the flotation system included hydraulic overflow rate (gpm/sq ft of tank area), pressurized flow rate, operating pressures, the addition of chemical flocculants, and the floated scum volumes. To investigate effluent pressurization as a method of improving the quality of effluent produced by the DAF unit, test conditions were selected to provide a common basis for comparisons between the modes of pressurized flow (i.e. split flow and effluent recycle). These test conditions were determined by the previous testing performed (Sections VI and VII), and were as follows:

pressurized flow (split flow)	20% raw flow
operating pressure	40-50 psig
overflow rate	3.3 gpm/sq ft
Chemical dosages	25 mg/l $FeCl_3$ 4 mg/l polyelectrolyte, cationic (C31 or equivalent)

It was planned to closely adhere to these test conditions while evaluating the effluent recycle mode of pressurized flow. The pressurized flow and the operating pressure could be adequately controlled to maintain these conditions. Because the flotation tank was divided into two separate areas, two overflow rates were obtainable concurrently. Therefore the raw flow rate was adjusted to obtain overflow rates which would be close to the optimum overflow rate of 3.3 gpm/sq ft. Previous studies had shown that at equivalent dosage rates, Nalco 607 was a satisfactory substitute for the cationic polyelectrolytes (C31) which was used previously.

The operational parameters monitored for the screening system included the hydraulic and solids loading rates, drum rotational speed, headlosses across the drum and the volumes of backwash required. Because the effluent from the flotation unit was automatically transferred to the screening system, the hydraulic loading rate was fixed. The solids loading rate and the attendant headlosses across the screen could be varied by adjusting the rotational speed speed of the drum. During the operating season this test plan was expanded to include the direct microscreening of raw CSO. During these test runs, the raw flow rate was varied to allow variations in the hydraulic loading rates.

A total of 10 overflow events were monitored at the Hawley Road test facilities during the 1973 operating season. The detailed analyses of the characteristics for each of these overflows is presented in Tables E-41 and E-42 in Appendix E. Each overflow was counted as a separate event over the entire length of the storm duration. No distinction was made between the first flush and the extended durations due to the short durations of most storms during the operational periods.

Consistent with previous observations, Appendix E. there was a wide variation in the raw CSO wastewater characteristics. The suspended solids concentrations of the raw CSO ranged from 39 to 276 mg/l during the 1973 operating season. Similar variations appear in the other pollutant parameters. A summary of the actual raw water quality concentrations sampled by each of the treatment systems is shown in Table 30. For comparison, previously reported (71) raw CSO characteristics are also presented. The ranges of data shown is at the 95% confidence level.

It can be readily seen that the pollutant levels of the raw wastewater for the 1973 season were, in general, lower than the corresponding pollutant levels of previous seasons. For example, influent suspended solids to the flotation system were only 146 ± 60 mg/l as compared to 244 ± 51 mg/l obtained during the 1969, 1970, and 1971 seasons. The suspended solids to the screening system were only 97 ± 80 mg/l.

The results of the screening/flotation unit operation are divided into the following two sections: coarse screening, and dissolved air flotation.

Coarse Screening

The raw flow entered the 50 mesh (297 micron) opening drum screen via a 1/2 inch opening bar rack. The bar screen removed the gross particulates and the 50 mesh screen removed most of the settleable particulates prior to flotation treatment. Complete results of the screening treatment are listed in Appendix E, Table E-17. A summary of the screened water quality is shown in Table 31.

Table 31. SUMMARY OF 50 MESH SCREENED WATER QUALITY - 1973
(95% confidence level)

Analysis	Concentration, mg/l
Total solids	269 ± 85
Total volatile solids	110 ± 37
Suspended solids	126 ± 57
Suspended volatile solids	44 ± 14
TOC	36 ± 15
BOD	36 ± 17

Particulate matter, as measured by suspended solids, ranged from 45 to 276 mg/l.

Table 30. COMBINED SEWER OVERFLOW CHARACTERISTICS - (1969-1973)
(95% confidence level) (mg/l except pH)

Parameter	1973 DAF system	1973 Screening system	1969-1971 DAF
pH	7.19 ± .2	7.21 ± .2	7.19 ± 7
Total solids	286 ± 99	336 ± 295	453 ± 63
Total volatile solids	117 ± 36	180 ± 206	211 ± 29
Suspended solids	146 ± 60	97 ± 80	244 ± 51
Volatile suspended solids	59 ± 19	46 ± 38	--
BOD	46 ± 20	33 ± 38	54.5 ± 13
TOC	43 ± 18	69 ± 88	--
Total Kjeldahl Nitrogen as N	5.8 ± 3.8	16.3 ± 30	5.86 ± 1.12
Total Phosphorus as P	1.18 ±.75	0.63 ± 46	
Ortho Phosphorus	--	--	.80 ± .19
Number of samples	9	4	53-65

A summary of the pollutant removals effected by the 50 mesh drum screen is presented in Table 32. For comparative purposes, removal rates obtained in previous operations are also shown. In general, removals by the drum screen during the 1973 season were lower than those obtained in past performances. The percent removals for various pollutants were in the range of 15 to 28%. No significant leaks in the drum screen were found that may have caused the lower removal efficiencies during 1973 operations, and the lower removal efficiencies could only be a result of a difference in particle size distribution of the particulate matter.

The backwash volumes ranged between 0 to 2.7% of the raw flow and averaged 0.8% for all runs during 1973. Some blinding problems were experienced on the screen media during prolonged dry weather periods. Such blinding could have been a result of microorganism growth and the screens were kept cleaned with periodic washes with sodium hypochlorite and/or dilute acid solutions.

Dissolved-Air Flotation Operation

As mentioned earlier, during 1973, the operation of the dissolved-air flotation system was conducted in the effluent pressurization mode compared to the split flow mode of pressurization during previous years. A complete listing of the operational parameters is included in Appendix E, Table E-23. Briefly, the surface hydraulic loading rates ranged between 2.7 and 3.9 gpm/sq ft on the low overflow rate side of the flotation tank to between 4.0 and 7.8 gpm/sq ft on the high overflow rate side. The pressurization flow ranged between 400 to 650 gpm representing 27 to 33% of the raw flow. Chemical treatment consisted of the addition of ferric chloride and Nalco 607, a cationic polymer. The average dosages of these chemicals based on the raw flow were 25 and 4 mg/l respectively.

A summary of the pollutant removal efficiencies of the screening/flotation system in terms of percent removals is presented in Table 33. A summary of the effluent quality from the flotation unit is presented in Table 34. Also presented are the comparative removals achieved by the system during the years 1969 through 1972, during which years the unit was operated in the split flow mode of pressurized flow. Comparing the percent removal efficiencies, there is no apparent difference in the overall system performance via the two modes of operation. For example, the suspended solids reductions in the effluent recycle mode ranged from 48 to 76% compared to 48 to 80% for the split flow mode of operation. Similarly, the percent removals of various other pollutant parameters were comparable for the two modes of operation. However, when the effluent quality data shown in Table 34 is compared for the two operation modes, the results are quite different. It can be readily seen that the quality of the DAF effluent during 1973 (using effluent pressurization) is significantly better than previous years (when split flow mode of pressurization was used). Since the concentration of pollutants during 1973 was generally lower than in previous years, and only 9 runs were made in effluent pressurization mode, it would appear that additional data is required to satisfactorily evaluate the performance of the effluent pressurization compared to split flow pressurization.

Table 32. POLLUTANT REMOVALS BY SCREENING DURING EXTENDED OVERFLOWS

Pollutant	1973[a]	1972[b]	1972[b]	1969-1970[a]
COD	--	--	--	26 ± 5
BOD	19 ± 18	20.0	34.5	27 ± 5
Suspended solids	19.6 ± 9.4	29.7	5.5	27 ± 5
Volatile suspended solids	27.9 ± 9.7	43.6	38.7	34 ± 5
TOC	15.4 ± 11.8	26.0	10.2	--
Number of samples	9	4	4	46

[a] Data at 95% confidence level

[b] Average removal

Table 33. POLLUTANT REMOVALS BY SCREENING/FLOTATION SYSTEM IN SPLIT FLOW & EFFLUENT PRESSURIZATION MODES AT LOW OVERFLOW RATES

	Effluent pressurization	Split flow			
Pollutant	1973[a]	1969[a]	1970[a]	1971[b]	1972[b]
COD	--	40 ± 14	57 ± 11	--	--
BOD	58 ± 19	46 ± 17	60 ± 11	58	61
Suspended solids	62 ± 14	59 ± 11	71 ± 9	60	55
Volatile suspended solids	65 ± 8	58 ± 10	71 ± [illegible]	43	57
Total nitrogen	24 ± 28	19 ± 11	24 ± 9	50	32
TOC	46 ± 17	--	--	51	54
No. of observations	9	38	38	5	3

a. Data at 95% confidence level
b. Average values.

Table 34. SCREENING/FLOTATION EFFLUENT QUALITY, (mg/l) - (1969-1973)
(95% confidence level)

Pollutant	1973		1970		1969
	Low overflow rate	High overflow rate	Low overflow rate	High overflow rate	Low overflow rate
Total solids	208 ± 66	202 ± 51	408 ± 79	433 ± 98	334 ± 63
Total volatile solids	91 ± 40	83 ± 29	184 ± 32	192 ± 38	161 ± 31
Suspended solids	52 ± 22	55 ± 28	60 ± 15	76 ± 20	76 ± 21
Suspended volatile solids	21 ± 8	19 ± 11	34 ± 8	41 ± 8	34 ± 7
TOC	25 ± 14	22 ± 9	--	--	--
BOD	20 ± 8	22 ± 10	26 ± 10	29 ± 10	27 ± 9
Total phosphate	0.5 ± .2	0.6 ± .3	0.5 ± .3[a]	0.5 ± .3[a]	1.3 ± .4[a]
Total Kjeldahl nitrogen	4.4 ± 2.3	2.8 ± 1.9	3.6 ± .6[b]	4.1 ± .8[b]	4.9 ± 1.2[b]
Dissolved organic oxygen	15 ± 9	--	--	--	--

a. Low overflow rate 2 to 4 gpm/sq ft
b. High overflow 4 to 8 gpm/sq ft

The mechanical operation of the screening/flotation system in general was excellent and no overflows were missed due to any mechanical problems. Maintenance was minimal and the system could be run with minimum supervision.

Flotation Effluent Screening

A listing of the operating conditions for the five test runs where the DAF effluents were processed through the 22 micron nylon microscreen is presented in Table 35 and in Appendix E, Table E-47. The influent flow to the microscreen (the entire flow from flotation unit) varied from 1687 to 2385 gpm. These flows corresponded to hydraulic loading rates of 27 to 37 gpm/sq ft. The solids loading rates, based on the suspended solids removed on the screen, were extremely low and varied between 0.16 and 1.68 lbs/100 sq ft. This loading is based on pounds of suspended solids in the flotation effluents per 100 square feet of wetted screen area.

The headloss across the screen generally varied between 12.5 to 13.5 inches of water. During run 73-5, however, th headloss briefly exceeded 14.5 inches of water and a portion bypassed the screening chamber via an overflow weir. Whenever this headloss exceeded 9 inches of water differential, the backwash pump was activated, indicating that the backwashing on the microscreen was kept "on" 100% of the operational time. The backwashing volume pumped during these runs ranged between 3.4-4.0% of the raw flow.

The results of the microscreening operation for the five storm events investigated are presented in Table 36. The influent concentrations were arrived at by averaging the results of the high and low overflow rate flotation effluents. Also, a summary of the percentage pollutant removals is presented in Table 37. The percent pollutant removals on the screen are presented both based on raw CSO as well as flotation treated effluent qualities. It can be seen that the microscreening unit removed approximately 20 to 40% (Table 37) of pollutants based on the influent quality coming into the microscreen. However, the incremental improvement in effluent quality due to microscreening over and above the flotation treatment was only 5 to 12% for suspended and volatile suspended solids while no improvement was recorded in TOC removals.

Based on these low incremental improvements in effluent quality, it was decided to curtail efforts to upgrade DAF effluent by microscreening and instead activities were directed towards evaluation of the use of the microscreening unit for the treatment of raw CSO.

MICROSCREENING OF RAW CSO

The necessary valving modifications were made to the microscreening system to allow treatment of the raw CSO instead of the flotation treated effluents. Five raw combined sewer overflows of the 1973 season were treated by the microscreening unit. A summary of the operational parameters for these five storms is shown in Table 38 and in Appendix E, Table E-47. The hydraulic loading rates ranged between 13 and 27.5 gpm/sq ft. The solids loading rates

Table 35. SUMMARY OF OPERATING CONDITIONS
MICROSCREENING FLOTATION EFFLUENT

	73-1	73-2	73-3	73-4	73-5
Influent flow rate, gpm	1,687	1,704	1,959	2,371	2,384
Raw flow volume, gal.	116,718	87,948	115,788	79,438	106,587
Drum speed, rpm	3.82	3.82	3.82	3.82	3.70-5.75
Average headloss across screen, in H_2O	13.00	12.75	12.95	13.00	14.00
% Screen wetted	---	---	63.3	63.5	64-6
Screen solids wading lbs/100 sq ft	0.16	1.68	0.16	0.34	0.60
Screen hydraulic loading, gpm/sq ft	27.10	27.48	34.07	40.96	37-48
Volume of backwash	---	---	3,980	3,195	3,655
Length of run, min	69.20	51.60	38.30	30.70	44.7

Table 36. SUMMARY OF WASTEWATER CHARACTERISTICS MICROSCREEN TREATMENT OF FLOTATION EFFLUENT (mg/l except pH)

Pollutant	Influent (DAF effluent quality)	Microscreen effluent quality
P[illegible]	7.14 ± .32	7.09 ± .27
Total solids	226.1 ± 65.4	221.2 ± 57.60
Total volatile solids	105.5 ± 39.4	98.4 ± 30.11
Suspended solids	62.7 ± 37.5	45.8 ± 24.93
Suspended volatile	26.1 ± 12.1	17.0 ± 10.68
TOC	30.4 ± 18.8	23.6 ± 3.30
BOD	27.3 ± 11.4	27.0 ± 13.18
Total phosphate	2.64 ± 0.38	0.47 ± 0.23
Kjeldahl nitrogen	5.70 ± 5.13	4.11 ± 2.02
Number of samples	4-5	4-5

Note: Range of values are 95% confidence level

Table 37. SUMMARY OF POLLUTANT REMOVALS BY MICROSCREENING OF FLOTATION EFFLUENT (%) (95% confidence level)

Pollutant	Percent removed by screen/flotation system based on raw quality	Percent removed by microscreen based on influent quality to microscreen	Overall percent removals by screening/flotation plus microscreening system based on raw quality
Suspended solids	57.47 ± 29.3	24.68 ± 20.8	66.59 ± 28.4
Suspended volatile solids	63.09 ± 8.0	38.00 ± 46.3	75.11 ± 16.5
TOC	40.94 ± 29.8	19.26 ± 32.8	43.08 ± 29.2
Total phosphate	51.4 ± 16.0	21.66 ± 19.0	51.43 ± 16.0
Kjeldahl nitrogen	17.72 ± 36.4	22.23 ± 33.7	25.48 ± 10.3

Table 38. SUMMARY OF OPERATING CONDITIONS FOR MICROSCREENING RAW CSO

	73-6	73-7	73-8A	73-8B	73-9	73-10
Raw flow rate, gpm	1,647	1,007	767	1,225	1,420	895
Raw flow volume, gal.	115,619	29,700	26,313	104,542	39,480	27,204
Drum speed, rpm	5.75	5.75	5.75	5.75	5.75	5.75
Headloss across screen, in H_2O	10.0	15	12.5	9	13.2	12.0
% screen wetted	60.9	64.7	62.4	60.4	62.4	61.5
Screen solids loading, lbs/100 sq ft	0.10	0.37	0.09	0.14	0.20	0.05
Actual screen hydraulic loading, gpm/sq ft	27.45	15.79	12.66	20.70	23.10	14.55
Volume of backwash	6,420	2,604	3,065	7,270	2,690	2,755
Length of run, min	70.2	29.5	34.3	82.6	32.2	30.4

were again quite low as shown in the table. A summary of the influent and effluent water quality data is presented in Table 39 and in Tables E-50 and E-51, Appendix E. It can be seen that the particulate concentrations in these five storms were extremely low. The suspended solids at 97 ± 80 mg/l at the 95% confidence limits were unusually low and contributed to the low solids loadings on the microscreen. The percentage pollutant removals on the microscreen are shown in Table 40. Also, presented in this table are the corresponding treatment efficiencies via the screening/flotation unit in the effluent recycle mode of operation. It can be seen that the mean pollutant removals via microscreening ranged between 35 to 57% for various parameters at the 95% confidence limits. The corresponding pollutant removal via flotation treatment were consistently better than microscreening and ranged between 50 to 67%.

POWDERED ACTIVATED CARBON ADDITION

The Hawley Road screening/flotation treatment facility was operated for ten overflow events from August 2, 1974 to October 29, 1974. The purpose of this effort was to determine the effect on screening/flotation effluent quality of using the addition of powdered activated carbon and chemical coagulants. The flotation unit was operated using the effluent recycle pressurization mode. The chemicals were added in the following order and at the following location points: alum and polymer in the screen chamber effluent followed by the activated carbon in the flocculator.

The following schedule of analytical tests was performed on each sample:

pH
Suspended solids (SS)
Volatile suspended solids (VSS)
Total solids (TS)
Total volatile solids (TVS)
Biological oxygen demand (BOD)
Total organic carbon (TOC)
Soluble organic carbon (SOC)
Total phosphorus

Sample analyses procedures are given in Appendix C.

The variables associated with the operation of the flotation system include the hydraulic overflow rate, pressurized flow rate, operating pressure, and the addition of chemical flocculants. To investigate powdered activated carbon addition as a method of improving the quality of effluent produced by the dissolved-air flotation unit, test conditions were selected on the basis of previous studies and the bench scale testing. The desired conditions were:

1. pressurized flow (effluent recycle) 25% of raw flow
2. operating pressure 40-50 psig
3. overflow rate 3.3 gpm/sq ft
4. chemical dosages 40 mg/l Alum
   0.5 - 1.0 mg/l Betz 1160
   40 mg/l Carbon

Table 39. SUMMARY OF INFLUENT AND EFFLUENT CHARACTERISTICS
FOR THE MICROSCREENING OF RAW CSO
(95% confidence level) (mg/l except for pH)
(22 micron screen size)

Pollutant	Influent	Effluent
pH	7.21 ± 0.2	7.21 ± 0.2
Total solids	336 ± 295	180 ± 90
Total volatile solids	180 ± 206	72 ± 56
Suspended solids	97 ± 80	64 ± 33
Suspended volatile solids	46 ± 38	29 ± 14
TOC	69 ± 88	26 ± 14
BOD	33 ± 38	23 ± 12
Total phosphate	0.63 ± 0.46	0.63 ± .34
Kjedahl nitrogen	16.3 ± 29.6	3.0 ± 1.3
DOC	44.6 ± 89.0	10.8 ± 4.4
Observations	3-6	3-6

Table 40. COMPARISON OF REMOVAL EFFICIENCIES
(95% confidence level)

	Microscreening, 22μ	DAF[a]
Total solids	38 ± 47	20 ± 30
Suspended solids	40 ± 22	67 ± 14
Suspended volatile solids	55 ± 24	67 ± 24
TOC	57 ± 71	49 ± 32
BOD	35 ± 55	56 ± 56
Observations	3-6	4

[a] DAF unit - Low overflow rate

It was planned to closely adhere to these conditions while evaluating the process with the addition of carbon. The pressurized flow and the operating pressure could be easily controlled to maintain these conditions. The chemical feed pumps were set for the desireo dosages and functioned well except for a couple of instances when pump problems caused addition rates less than desired. For previous studies at the Hawley Road site, the flotation tank was divided into two modules. This allowed for the simultaneous study of a high overflow rate and a low overflow rate. For this study, however, the divisions were removed resulting in one flotation zone and one overflow rate.

It was intended to run the facility at a flow rate of 3 MGD, however, it was found that the drum screen could not handle the flow at this rate. Therefore, the site was run at the highest rate possible that would not hydraulically overload the drum screen.

The means and ranges for the operating conditions during the ten runs in 1974 are given in Table 41. The operating conditions are given on a run-by-run basis in Appendix E, Tables E-31 through E-40.

A total of 10 overflow events were monitored at the Hawley Road facility during the 1974 operations. The quality characteristics of the combined sewer overflows on a run-by-run basis are presented in Appendix E, Tables E-31 to E-40. A summary of the combined sewer overflow quality concentrations is presented in Table 42. For comparison, previously reported combined sewer overflow quality characteristics are also presented. The ranges given for the means are at the 95 % confidence level.

It can be seen that the pollutional concentrations of the combined sewer overflows for 1974 have increased when compared to the concentrations found in 1973. Except for the suspended solids concentrations, they have also shown a slight increase compared to the concentrations found in 1971-72.

The ranges given at the 95 percent level of confidence are all greater than those found in 1973 or 1971-72. This indicates that the quality concentrations found in 1974, in addition to being higher on the average, were much more variable than those encountered in 1971-72 and 1973. This high variation in concentration in conjunction with the low sample number (10) made it difficult to show significant statistical differences between the means for 1974 and the means from 1971-72 or 1973.

The increase in the mean pollutional concentrations of the combined sewer overflows also affected the removal calculations (effluent concentrations increased but percent removals also increased) which will be discussed later in this section.

The screened overflow quality characteristics are given on a run-by-run basis in Appendix E, Tables E-31 to E-40. The mean quality characteristics of the screened combined sewer overflows in 1971-72, 1973, and 1974 are given in Table 43. Also presented are the pollutional percent removals achieved by the screen in 1971-72, 1973, and 1974. As with the raw overflow, the screened overflow was of a higher pollutional concentration than in 1973. The percent removals for 1973 and 1974, however, were similar. The mean concentrations

Table 41. AVERAGE OPERATIONAL PARAMETERS FOR DISSOLVED-AIR FLOTATION PROCESS - 1974

	Mean	Range
Flow rate		
Raw, gpm	1866	1362-2205
Recycle, gpm	540	400-700
Total, gpm	2406	1987-2705
Recycle rate, percent	29	21-46
Hydraulic overflow rate		
Raw, gpm/sq ft	2.38	1.74-2.83
Total, gpm/sq ft	3.10	2.56-3.46
Chemical dosages		
Alum, mg/l	35	18-63
Carbon, mg/l	50	26-94
Polyelectrolyte, mg/l	0.9	0.11-1.7

Table 42. COMBINED SEWER OVERFLOW QUALITY CHARACTERISTICS (1971-1974) (mg/l) (95% confidence level)

Parameter	1971-72	1973	1974
SS	230±97	129±62	162±101
VSS	75±28	52±21	87±68
TS	347±100	255±75	409±195
TVS	158±79	108±36	213±108
BOD	34±18	42±19	74±64
TOC	45±15	39±17	58±42
SOC	--	17±7	25±10
Total phosphorus	--	0.99±0.51	1.47±0.73

Table 43. SCREENED EFFLUENT QUALITY CHARACTERISTICS (mg/l) AND PERCENT REMOVALS BY THE SCREENING PROCESS - (1971-1974) (95% confidence level)

Parameter	1971-72	1973	1974
SS	204±118	126±58	132±57
VSS	71±41	44±15	68±35
TS	493±220	269±85	322±134
TVS	227±68	110±37	173±68
BOD	23±16	37±17	51±26
TOC	39±15	36±15	46±20
SOC	--	--	23±10

Parameter	Percent Removal		
	1971-72	1973	1974
SS	12	13	16
VSS	16	22	14
BOD	28	15	15
TOC	9	11	13
SOC	--	--	17

were compared among the three different study periods and no statistically significant differences were found. The mean percent removals were also compared among the three periods and again no statistically significant differences (increase or reduction) were found.

As discussed previously, in 1974 the operation of the dissolved-air flotation system was conducted in the effluent pressurization mode with the addition of alum, polyelectrolyte, and powdered activated carbon. In 1973, the system was operated in the effluent pressurization mode with the addition of ferric chloride and polyelectrolyte, and in 1971-72, in the split flow pressurization mode with the addition of ferric chloride and polyelectrolyte.

The average 1974 operating conditions are given in Table 41. The raw flow rate averaged 1.87 MGD with a range of 1.36 to 2.21 MGD. The recycle rate averaged 0.54 MGD and ranged from 0.40 to 0.70 MGD. This resulted in an average recycle rate of 28.9 percent of the raw flow and a range of 21.4 to 45.9 percent. The hydraulic overflow rate averaged 2.95 gpm/sq ft with a range of 2.56 to 3.46 gpm/sq ft. The chemical treatment consisted of the addition of alum, average dosage of 35 mg/l; powdered activated carbon, average dosage of 50 mg/l; and polyelectrolyte (Betz 1160), average dosage of 0.9 mg/l.

A summary of the pollutional percent removals achieved by the dissolved-air flotation unit is presented in Table 44. Also presented are the comparative removals achieved by the system during the testing periods in 1971-72 and 1973. Statistical comparison of the percent removal efficiencies again revealed no significant differences among the three periods of study.

The final effluent quality characteristics from screening/flotation are given on a run-by-run basis in Appendix E, Tables E-31 to E-40. The mean quality characteristics of the final effluent, and the mean percent removals achieved by the overall system are given in Table 45 for 1971-72, 1973, and 1974.

It can be seen from Table 45 that the quality of the effluent in 1974 is similar to the effluent quality in 1971-72, but less than the quality achieved by the screening/dissolved-air flotation process in 1973. On the other hand, the pollutional percent removals for 1974 are also similar to those achieved in 1971-72 but they are better than the percent removals attained in 1973.

The increase in percent removals and in effluent concentrations is attributed to the increase in the raw quality concentrations in 1974 compared to 1973. The high pollutional concentrations in the raw combined sewer overflows in 1974 led to better percent removals than in 1973, but these increased percent removals did not result in improved final effluent quality over the quality achieved in 1973. In fact, the quality of the effluent decreased in 1974. Comparing 1973 to 1974, the average effluent SS increased from 22 to 37 mg/l, the total solids increased from 208 to 321 mg/l, the BOD increased from 20 to 28 mg/l, and the TOC increased from 25 to 33 mg/l. Statistical analyses indicated that these changes were not significant at the 95 percent confidence level, but the overall pattern does indicate that an actual increase did occur. The lack of statistical significance is probably due to the low number of observations made (8 or 9 samples for the given parameters in 1973 and

Table 44. PERCENT REMOVALS BY THE DISSOLVED-AIR FLOTATION PROCESS - (1971-1974)

Parameter	Percent Removals 1971-72	 1973	 1974
SS	59	49	54
VSS	49	49	47
BOD	43	41	56
TOC	49	31	37
SOC	--	--	32

Table 45. FINAL EFFLUENT QUALITY CHARACTERISTICS AND PERCENT REMOVALS BY THE SCREENING/DISSOLVED-AIR FLOTATION PROCESS-(1971-1974)

Parameter	1971-72	1973	1974
SS	87±38	52±22	58±37
VSS	39±18	21±7	35±29
TS	401±154	208±66	321±130
TVS	191±78	91±40	172±63
BOD	13±8	20±8	28±27
TOC	20±9	25±15	33±25
SOC	--	15±9	16±8
Total Phosphorus	--	0.47±0.19	0.52±0.37

Parameter	Percent Removals		
	1971-72	1973	1974
SS	58	54	60
VSS	48	60	56
BOD	59	46	65
TOC	52	35	45
SOC	--	16	38
Total Phosphorus	--	47	65

Note: Intervals given are at the 95 percent level of confidence.

9 samples in 1974).

Statistical comparison of the 1971-72 and 1974 means, both effluent concentrations and percent removals, showed no significant differences. No patterns were obvious from observation of the data either, because of some percent removals improving while the concentration in the effluent also increased. Better SS, VSS, and BOD percent removals were achieved in 1974 than in 1971-72 while the percent removal of TOC was better in 1971-72. In 1974, the final effluent SS, VSS, total solids, and total volatile solids concentrations were lower than those found in 1971-72, but the final effluent BOD and TOC concentrations were higher than in 1971-72. Therefore, no significant improvement in the efficiency of the screening/dissolved-air flotation process can be shown due to the change from split flow pressurization with ferric chloride and polyelectrolyte addition (1971-72) to effluent recycle pressurization with alum, powdered activated carbon, and polyelectrolyte addition (1974).

The percent removals of soluble organic carbon (SOC) and total phosphorus do show marked improvements in 1974 when compared to 1973. The improvement in the SOC percent removal is statistically significant at the 95 percent level of confidence. The effluent concentrations of both total phosphorus and SOC, however, were higher in 1974 than 1973, but the increase in the average SOC concentration, 1 mg/l, is very slight compared to the increases observed for the other quality parameters.

The effectiveness or noneffectiveness of the powdered activated carbon addition is not clearly shown by the results from the study. There was a significant improvement in the percent removal of SOC and a corresponding increase in the percent removal of TOC, but at the same time, the average effluent concentration of TOC increased from 25 to 33 mg/l and the SOC concentration increased from 15 to 16 mg/l. The corresponding increases in the raw flow were: TOC, 39 to 58 mg/l, and SOC, 17 to 25 mg/l. It does appear that the addition of powdered activated carbon did improve the percent removal of the soluble portion of the total organic carbon, and this improved removal did prevent the effluent SOC concentration from increasing as much as the effluent concentrations of the other parameters when the combined sewer overflow pollutional strength increased in 1974. However, the improvement of the SOC percent removal, 16 to 38 percent, cannot be entirely attributed to the addition of the powdered activated carbon. The percent removals of many of the other parameters also increased; apparently because of the increased concentrations of the parameters in the raw overflow. For this reason, it is difficult to make a judgement on the magnitude to which the powdered activated carbon was responsible for the improvement in the percent removal of SOC by the screening/dissolved-air flotation process.

The same problem also affects the improvement in the percent removal of total phosphorus in 1974 when compared to 1973. How much of the improved removal is due to the addition of alum, and how much is a consequence of increased phosphorus concentrations in the raw combined sewer overflows? It appears that the addition of alum helped in improving the percent removal of phosphorus, 47 to 65 percent, but the improvement cannot be quantified from the data available.

During the course of the study in 1974, one run at the Hawley Road facility was conducted without the addition of carbon (Run No. 7, Table E-37, Appendix E. The intention was to compare this run with the others for which carbon was added. The very low pollutional strength of the overflow (SS: 42 mg/l; BOD: 15 mg/l; and TOC: 18 mg/l), however, made comparisons on a percent removal basis difficult. The effluent concentrations (SS: 29 mg/l; BOD: 14 mg/l; and TOC: 13 mg/l) may indicate the minimum effluent concentrations that can be practically achieved by the screening/dissolved-air flotation process.

Any consideration of the use of powdered activated carbon to improve the treatment efficiency of the screening/dissolved-air flotation process must take into account the increased costs that are required to achieve the improved efficiency. The use of alum and polyelectrolyte (Betz 1160) as the chemical flocculants resulted in a chemical cost of 3.94¢/1,000 gal. treated. This was for addition rates of 35 mg/l of alum and 0.9 mg/l of polyelectrolyte. The addition of 50 mg/l of powdered activated carbon increased the cost by 8.55¢/1,000 gal. for a total chemical cost of 12.49¢/1,000 gal.

The percent removals in 1974 did show an increase when compared to the 1973 results. BOD removal increased from 46 to 65 percent, TOC removal increased from 35 to 45 percent, and SOC removal increased from 16 to 38 percent. The percent removals in 1974, however, do not show such a marked increase when compared to the 1971-72 results. BOD removal increased from 59 to 65 percent, but TOC removal dropped from 52 to 45 percent. For all three periods the SS removals remained fairly constant (approximately 58 percent).

The percent removals tend to show a benefit from the addition of powdered activated carbon, but the quality of the final effluent was not improved. From 1973 to 1974 the BOD concentration increased from 20 to 28 mg/l, TOC increased from 25 to 33 mg/l, and SOC increased from 15 to 16 mg/l. Effluent BOD and TOC concentrations were also greater in 1974 when compared to 1971-72, BOD increased from 13 to 28 mg/l and TOC increased from 20 to 33 mg/l.

The results of the field testing are inconclusive as far as quantifying the benefits of powdered activated carbon addition to the efficiency of the screening/dissolved-air flotation process. However, because the improvements in the percent removals, except SOC, were not statistically significant; because part of the improvement in the percent removals may be due only to an increase in the pollutional concentrations in the raw flow; because the quality of the final effluent was not improved; and because of the high cost of the powdered activated carbon addition, 8.55¢/1,000 gal.; it is indicated that the benefits achieved do not justify the significant increase in the cost.

To further establish the actual effectiveness of carbon addition, further field testing would be required, but the results of this project indicate that carbon addition may not significantly improve the efficiency of the screening/dissolved-air flotation process in removing SOC to the point that would justify the high cost of the chemical additions required.

SECTION XI

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SECTION XII - APPENDICES

APPENDIX A - CHEMICAL OXIDATION STUDIES

LITERATURE SEARCH

Removal of organic contaminants from combined sewer overflows cannot be effectively and economically accomplished by conventional biological oxidation methods (A1) (A2) for the following reasons:

A. Large and highly variable flows.
B. Intermittent operation would be required because of the nature of the flows, and this has a very detrimental effect on biological oxidation systems (A3)(A4)(A5).
C. Removal of the solids produced would require a large number of sedimentation tanks (because of high flows) which would be used only periodically.

Use of chemical oxidation on combined overflows has the potential advantage of effective destruction of biological organisms and the removal of organic contaminants without the production of residual waste concentrates. Some of the technical difficulties connected with the successful treatment of wastes by chemical oxidation include the relatively dilute concentrations of organic materials present, the unknown composition of a wide range of possible organic compounds present, and the continually changing concentrations and composition present in a combined wastewater flow such as the one which this project is concerned.

These difficulties necessitate the use of gross parameters in evaluating the effectiveness of a given chemical oxidant. Such parameters would include knowing the chemical oxygen demand of the waste (COD) and the concentration of the oxidizing properties in the chemical being utilized. Having this information, the oxidation efficiency (A6) can be calculated as shown below:

$$\text{Oxidation Efficiency} = \frac{\Delta\text{COD}}{\text{Available Oxidation Equivalents} \times 100}$$

Where: ΔCOD = change in COD brought about by the oxidation process (in milligrams of O_2 per liter)

And: Available Oxidation Equivalents = amount of chemical oxidation equivalents available from the oxidant used (in milligrams of O_2 per liter)

Taking into account the variation in organic concentration and volume of the waste flow to be treated under this contract, the "ideal" oxidant should have the following characteristics:

A. It must be nonspecific in its attack on organic materials.
B. Its required contact and retention time should not be excessive (30 minutes or less).
C. It should be easy to handle and dispense.
D. It should effectively oxidize the organic materials at the prevailing pH of the waste.
E. It should not produce any secondary pollutants which are difficult to remove from the waste flow.

From the literature (A6) it was found that six types of oxidation systems offer various degrees of potential for the treatment of organic impurities in wastewater. These systems are:

A. Oxidation by oxidants containing active oxygen.
B. Accelerated molecular oxygen oxidation.
C. Catalytic oxidation of adsorbed organics.
D. Oxidation by chlorine and its derivatives.
E. Oxidation by oxy-acids and their salts.
F. Electrochemical oxidation.

Of the six oxidation systems mentioned, only systems A, D, E, and F appear to have potential for treating combined sewer overflows. These systems will be discussed in detail below.

Hydrogen Peroxide

Considerable work has been done regarding the application of hydrogen peroxide (H_2O_2) as an oxidizing agent in the treatment of wastewater containing organic impurities (A6)(A7)(A8)(A9)(A10)(A11)(A12).

In aqueous media, hydrogen peroxide decomposes to form the $\cdot OH^-$ radical. This radical is one of the strongest oxidants known in aqueous systems. However, hydrogen peroxide does not, when used alone, oxidize organic materials within a practical reaction time. The system requires a multivalent iron salt as a catalyst.

The principle reactions involved in a hydrogen peroxide iron salt system are as follows: (A11)(A12)

1. $Fe^{+++} + H_2O_2 \rightarrow Fe^{++} + HO_2 + H^+$

2. $Fe^{++} + H_2O_2 \rightarrow Fe^{+++} + OH^- + \cdot OH$

Considering reactions 1 and 2 above, the iron salt acts truly as a catalyst i.e., it is not utilized during the reactions. Reaction 1 is the rate limiting reaction. Once the ferrous ion is formed, reaction 2 is extremely rapid (A11)(A12). The production of ·OH radicals via reactions 1 and 2 using ferric salts requires two to three hours at 65°C (A6). By using ferrous salts, the production of ·OH radicals is essentially immediate, but the iron salt no longer performs as a true catalyst, since it is not reproduced at the same rate at which it is being utilized. There are other reactions associated with the H_2O_2--iron salt system which compete with the organic material being oxidized for the ·OH radical. The following reactions illustrate the competition for ·OH radicals (A11)(A12).

3. $FE^{++} + \cdot OH \rightarrow Fe^{+++} + OH^-$

4. $HO_2 \rightleftarrows O_2^- + H^+$

5. $Fe^{+++} + O_2^- \rightarrow Fe^{++} + O_2$

6. $H_2O_2 + \cdot OH \rightarrow HO_2 + H_2O$

Hence, only an unknown portion of the ·OH radicals produced are available to oxidize the organic substrate.

The efficient production of ·OH radicals requires a specific pH range of 3 to 5 (A6)(A7)(A10)(A11). Above or below this specific pH range, production of ·OH radicals is greatly reduced. During the reactions, an excess of H^+ ions are formed (A9) so the pH will normally stabilize in the optimum range. Eisenhauer (A7) found that the initial pH of an ABS solution could be as high as 11, before it would significantly affect pH stabilization in the 3 to 4 pH range. The pH of the system can also be lowered to the specific range by use of acid (A11).

The reactions between ·OH radicals and specific organic substrates were summarized by Busch (A12) after review of a number of papers on the subject. Since the waste to be oxidized under this contract contains many different types of organic substrates in unknown proportions, these specific equations were not directly applicable and hence were not reproduced herein.

Use of the hydrogen peroxide method of oxidizing organic wastes has been experimentally evaluated. Davidson found that phenols could be chemically oxidized (90% complete) to carbon dioxide and water in ten minutes (A9). Eisenhauer demonstrated that in dilute aqueous solutions of phenol, the reaction efficiency was considerably increased in the presence of air-available oxygen (A7).

Eisenhauer also found that the reaction between a hydrogen peroxide-ferrous salt combination and Acrylonitrile Butadiene Styrene Polymers was rapid and 80 to 90% of the ABS was destroyed in the first ten minutes. Further ABS removals were obtained at slower reaction rates, with a 99% ABS removal effected after fifteen to twenty hours. The optimum reaction pH level was found to be from 3.0 to 3.5. The optimum concentrations of the reactants were six moles of ferrous salt per mole of ABS, and nine moles of H_2O_2 per mole of ABS. Multiple incremental additions of the ferrous salt will decrease the reaction time required (A11).

Applying this information to a treatment of laundry wastes containing ABS, Eisenhauer obtained ABS reductions in excess of 90%, both with the raw waste and with effluent from a pretreatment process in which the detergent builders were precipitated. For a laundry waste containing 50 to 80 parts per million ABS, it was found that chemical costs ranged from \$0.45 to \$0.70 per 1,000 gallons for the effluent pretreated with ferric sulfate. This includes the cost of ferrous sulfate, ferric sulfate, sulfuric acid, and hydrogen peroxide (A7).

Bishop et al (A11) used hydrogen peroxide-iron salt systems to oxidize refractory organics in municipal wastewaters previously subjected to secondary biological treatment. Significant conclusions from this paper (A11) are presented below.

1. The hydrogen peroxide-iron salt systems in various wastewaters oxidize a significant portion (≈70%) of the organics refractory to biological oxidation.

2. The oxidation process involves free radical ($^{\cdot}OH$) oxidation and auto-oxidation and is effective only in the pH range of 3 to 4.

3. Oxidation efficiencies of 60% for the ferric ion systems and 30 to 51% for the ferrous systems were reported.

No data were found in the existing literature where hydrogen peroxide was used to oxidize raw sewage or combined sewer overflow. Since the H_2O_2 systems did oxidize the refractory organics present in sewage, there should be no problem oxidizing the organics in combined sewer overflow. The important problems associated with the use of this oxidation system for combined sewer overflow include:

1. The restricted pH range will require lowering of the pH of the combined sewer flow.

2. Materials used for construction will have to be able to withstand the pH of the system. This will require the use of stainless steel, or rubber coated mild carbon steel.

3. Removal of the ferric hydroxide formed during the reaction will require a flocculation and settling period.

4. The pH will have to be readjusted to near neutral before the effluent is discharged.

Ozone

The use of ozone as an oxidant for water and waste treatment is described in the literature (A6)(A13)(A14)(A15)(A16)(A17)(A18)(A19)(A20)(A21). Ozone is a blue gas under normal conditions. It contains three atoms of oxygen (O_3) and is heavier than air or oxygen. Ozone is one of the most powerful oxidants known (A13). The oxidizing power of ozone is exceeded only by fluorine and compounds such as oxygen difluoride, atomic oxygen, and the hydroxyl radical (A22). In high concentrations, ozone is toxic (A13)(A14). Figure A-1 shows the human tolerance for ozone at various concentrations and exposure times.

Source: Prolonged Ozone Inhalation, Its Effects On Visual Parameters, J. M. Langewerf, Aerospace Medicine, 36, June 1963.

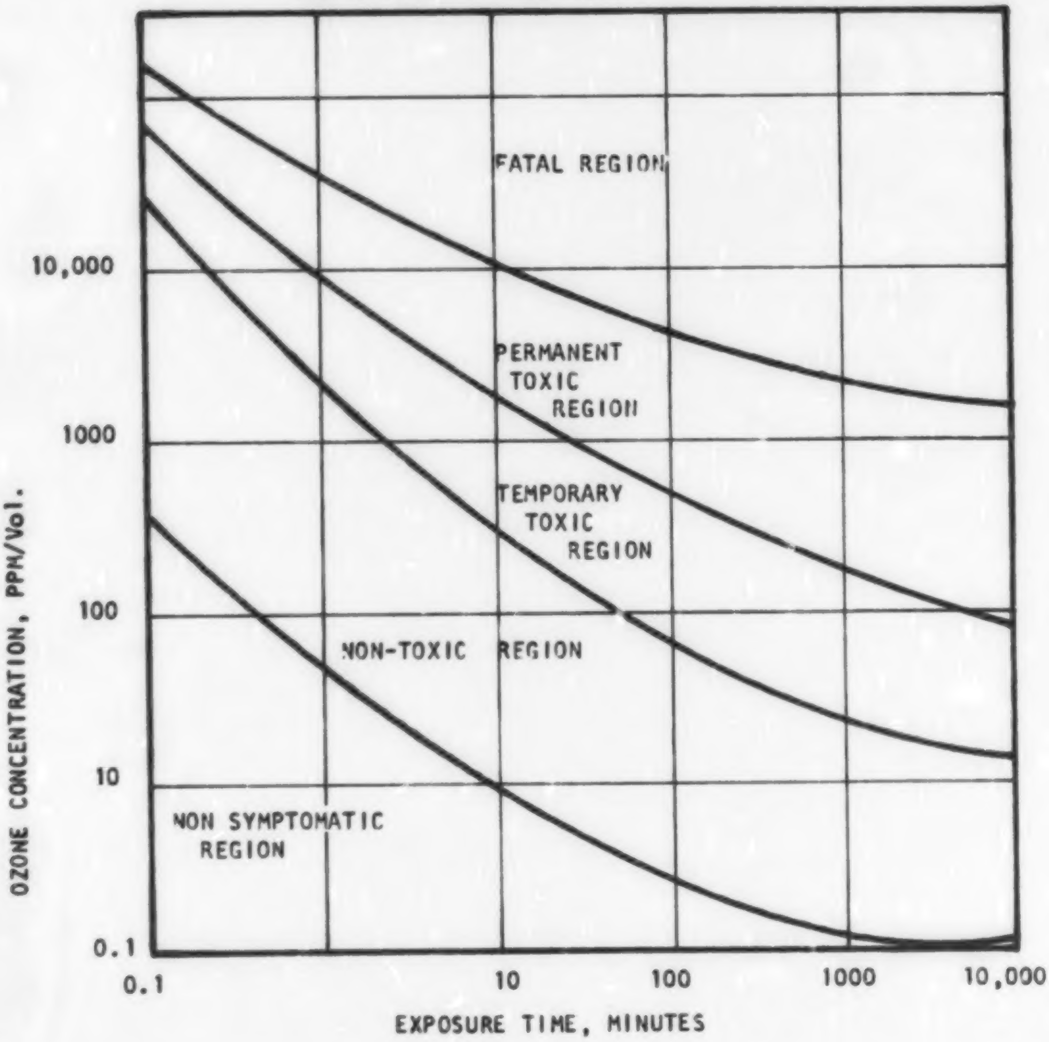

Figure A-1. Human tolerance for ozone

The area between the symptomatic line and irritant line of Figure A-1 is a nontoxic region. The threshold odor level of ozone is 0.01 to 0.02 ppm which is well below the toxic region as shown in Figure A-1 (A13). Exposed persons are thus given a warning of ozone's presence.

Ozone can be produced in a number of ways. Among these are silent electric discharge, electrochemically, and chemically (A22). Use of silent electric discharge is the principal upon which most laboratory and large scale ozonizers depend (A13)(A22). Production of ozone by this method requires the use of cold, clean air or oxygen Basic equipment necessary include an air fan, equipment for filtering and drying the air and an ozonizer (A14). When applying the ozone to water, some type of diffuser system and a contact tank will also be needed (A14). Ozonizers produce ozone by passing the dried air between two concentric electrodes separated by a dielectric. High frequencies (500 cps to 1000 cps) and high voltages (4000 to 30,000 volts) are utilized. Some oxygen in the air passing through the ozonizer is broken into charged oxygen atoms, which recombine to form O_3. Ozonizers operating on air under pressure produce far greater quantities of ozone in higher concentrations than those operating in air at atmospheric pressures (A13)(A17). Commercial ozonators produce ozone concentrations of 1 to 4 percent by weight in air (A17)(A23). Power consumption is 9.5 to 11.5 KWH per pound of ozone produced (A23).

Ozone is very corrosive and hence the materials used in the piping system carrying ozonated air must be carefully chosen. Porcelain has been used with success, as have aluminum, stainless steel, pressboard, oak, vinyl plastic and glass (A14)(A24). Polyvinyl chloride (PVC) has been used but there is a possibility that this material decomposes ozone (A14).

The exact oxidation mechanism of ozone on organic materials is not thoroughly understood. Ozone decomposition may be a source of ·OH radicals or the O_3 itself may be the actual oxidant (A6)(A21). Ozone is known, however, to be an effective oxidant (A17)(A18)(A21). The exact oxidation products and intermediates resulting from ozone oxidation have not been defined. Evans and Ryckman (A18) , when ozonating secondary sewage treatment plant effluents have found that ozone readily oxidized ABS to intermediate compounds which were not detected by an ABS analysis. These intermediates actually caused an increase in BOD and COD values of the partially ozonated waste, and in fact destroyed the biological inertness of the ABS. Increased ozonation of this partially ozonated waste then caused a decrease in BOD and COD of the waste, apparently due to oxidation of some of the organic carbon to CO_2 and H_2O.

Andrews (A16) was recently granted a patent on a new method of treating raw sewage. The method involves removal of the solids from raw sewage by a combination of settling, screening, and centrifuging. The resulting liquor, essentially free of solids and containing the soluble BOD fraction of the raw sewage, is ozonated to oxidize the BOD. The effluent from ozone treatment is filtered before discharging into the receiving stream.

The patent claims this treatment method produces a clear, colorless effluent, free from bacteria, and containing a high quantity of dissolved oxygen. However, no reference is made to ozone dosages required and BOD effluent content.

Miller (A21) reports use of ozone to control sewer odors at sewage lift stations. He states ozone addition reduced the raw sewage BOD from 120 to 32-39 mg/l. Septic conditions in flat sewers disappeared and the plant influent contained 2 to 4 mg/l of dissolved oxygen. No mention was made of the quantities of ozone added. The ozone was injected directly into the pump wet wells for conventional lift stations and into the air compressors supplying air for the pneumatic-ejector type lift stations.

March and Panula (A15) reported on a study where raw sewage was ozonated. They report that the BOD of the sewage which was ozonated decreased from 400 to 300 mg/l. Application rate was 6 mg/l of ozone actually absorbed by the sewage. This indicates that 1 mg of O_3 will oxidize about 16 mg of BOD which seems quite high. The amount of O_3 applied during this study was greater than the amount actually utilized. Absorption efficiencies averaged 22.6%. Hence, the actual ozone dosage was about 26 mg/l. March and Panula (A15) indicate that the biggest problem in full-scale ozone treatment is efficient use of the ozone being produced. They suggest collecting the unabsorbed ozone and reapplying it to the sewage to obtain better absorption efficiencies. It should be noted that a simple diffusion system was used during this study with a 3½ foot depth of liquid over the diffusers. Bubble size was on the order of 0.01 inches in diameter.

O'Donovan (A14) stresses the importance of mixing techniques when introducing ozone into water. He stresses small bubble diameter and turbulence to be important in obtaining good O_3 absorption efficiencies. Two types of absorption systems which have been used are illustrated in Figure A-2 (A14)(A25). Campbell (A25) reports 90% utilization of ozone when using a partial-ejection system.

The use of ozone to oxidize combined sewer overflow appears to hold considerable promise. Ozone has many of the characteristics of the "ideal oxidant" as previously discussed. It is apparently nonspecific in its oxidation of organic material (A21), the necessary contact time is less than 30 minutes (A14)(A25), it oxidizes at the prevailing pH of the waste (A25), and is not difficult to dispense (A14). Some disadvantages involved with the use of ozone include precipitation of iron and manganese when present in concentrations greater than 0.2 mg/l Fe and 0.1 mg/l Mn, inability to carry an ozone residual for significant periods, and inability to store ozone requires ozonators at each application site. Recently, however, Matheson Inc. has announced it had a process which will allow storage of ozone which could eliminate this latter disadvantage.

Oxidation by Chlorine

Chlorine or its derivatives are added to most municipal water supplied in the United States to kill micro-organisms. Green and Stumpf (A26) have shown that chlorine compounds react with certain enzymes which are essential to the metabolic process of living cells and that death results from the inactivation of these enzymes. Dosages required for disinfection are low, 0.2 to 2 mg/l (A1).

Use of chlorine to reduce the BOD of sewage has been practiced. Four kinds of

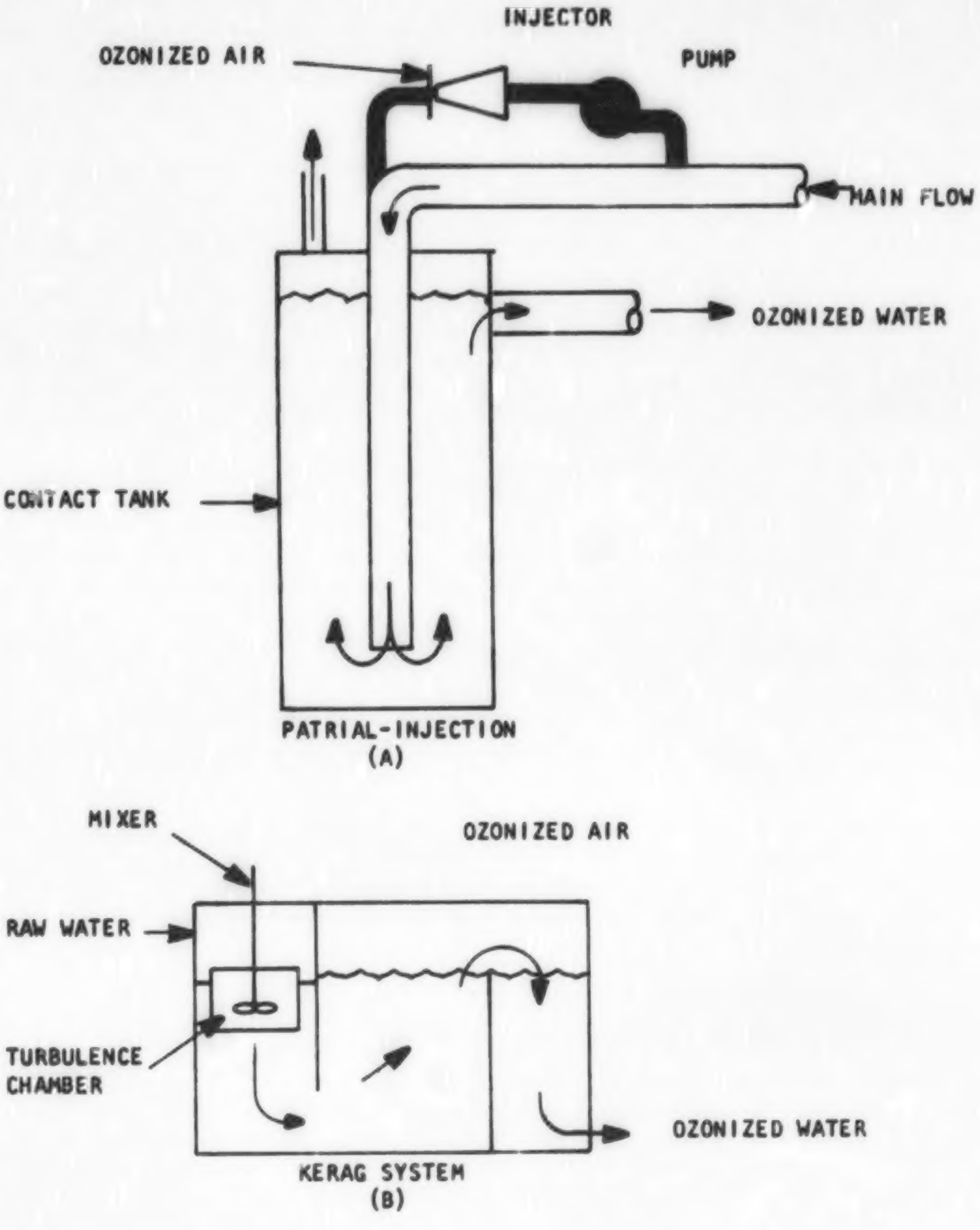

Figure A-2. Ozone absorption systems

reactions could be involved in reducing BOD by chlorination (A1)(A27).

1. Direct oxidation of organic materials.
2. Substitution of chlorine for hydrogen which produces compounds which have a bactericidal power.
3. Substitution of chlorine for hydrogen which produces compounds which are no longer biologically degradable.
4. Addition of chlorine to unsaturated compounds forming nonbiodegradable substances.

Griffin and Chamberlin (A28) have shown that chlorination of sewage does result in a reduction of BOD. After an 18 hour contact period, about 35% of the BOD had been removed from screened raw sewage at a 200 mg/l chlorine dosage. Increasing the dosage had little effect on further removals.

Although chlorine and its derivatives do oxidize many of the organic chemicals contained in municipal wastewaters, they do not usually convert them to the readily acceptable forms of carbon dioxide and water (A6). Instead, the reaction of chlorine with organics may produce molecules having considerable taste and odor, and complex compounds which serve as secondary pollutants may also be formed. The addition of stoichiometric amounts of chlorine will not effect oxidation of the organics, and a large chlorine residual may remain in the treated waste (A6)(A28). Since oxidation by chlorine is far less effective than by active-oxygen elements and since the unknown by-products of chlorine oxidation may be toxic, chlorine and its derivatives are not considered to be good prospects for removal of large amounts of organic pollutants from wastewaters by oxidation (A6).

A method of making chlorine more reactive could, however, make the use of chlorine more attractive. Use of ultraviolet radiation to catalyze the oxidation of organic material by chlorine has been suggested (A29). No specific data on such a process was found in the literature, but the process will be investigated during the laboratory phase of this study.

Oxidation by Oxy-Acids and Their Salts

The oxy-acid oxidants are usually added to aqueous systems as the salt of the oxy-acid. Important oxy-acid salts with high oxidation potentials include potassium permanganate ($KMNO_4$), sodium ferrate ($NaFeO_4$) and potassium ferrate (K_2FeO_4). The oxidation potentials of the oxy-acids are strongly dependent upon the acidity of the aqueous system, with the potential increasing as the acidity increases (A6).

Potassium permanganate ($KMNO_4$) is used as an oxidant to disinfect water supplies (A1)(A30) and as an oxidizing agent in the permanganate oxygen demand test (A31). However, references in the literature report only limited oxidation of organics with $KMNO_4$, and a residual permanganate persists in the water for more than twenty-four hours (A30)(A31). Vosloo (A32) reports that the permanganate concentration necessary for maximum oxidation should be about twice the concentration of permanganate which will be utilized. The use of potassium permanganate would therefore require removal of the excess MNO_4^- ion as a part of the treatment process, and this would greatly increase the salt load in the aqueous system (A6). The potential for using $KMNO_4$ as an oxidant in this project is not at all promising, and hence, $KMNO_4$ oxidation will not be considered.

Although ferrate salts such as potassium ferrate (K_2FeO_4) are not commercially produced, their high oxidation potentials (A33) and the coagulating properties of their oxidation products, a highly insoluble ferric hydroxide, make the ferrates a potentially attractive group of oxidants for treatment of wastewaters (A6).

Exploratory laboratory tests using K_2FeO_4 to treat filtered municipal secondary effluents in dosages supplying approximately 100 milligrams per liter of available oxygen showed the combination of ferrate oxidation and coagulation to be nearly as effective as the previously discussed H_2O_2 - Iron salt system for removing organic materials from wastewaters (A6). The ferrate salts, however, also possess the same disadvantages as the H_2O_2 iron salt system, (see previous discussion on hydrogen peroxide oxidation) and these disadvantages must be considered when attempting to use the ferrate salts as oxidants in this project.

Electro-Chemical Oxidation

Any material that increases the electrical conductivity of an aqueous solution may enter into a chemical reaction at the surface of electrodes placed in the solution (A27). Interest in electrochemistry as a possible technique for purifying municipal wastewaters is based on the fact that many organic chemicals take part in such electrode reactions, often resulting in the complete degradation of complex organic molecules to carbon dioxide, water and other oxides. After reviewing a recent study on electrochemical oxidation (A34), it was concluded that electrochemical oxidation did not hold potential for treating combined sewer overflows for the following reasons:

1. High operating and maintenance costs.
2. Formation of precipitates which would have to be removed from the waste flow.
3. Long reaction times are necessary -- 2 to 5 hours.

Combination of Oxidants

Although no specific data were found in the literature about combining various oxidants, a combination of ozone and H_2O_2 or other combinations may produce an effective oxidation system. For this reason, various combinations of oxidants will be evaluated during the laboratory phase of this project.

LABORATORY INVESTIGATIONS

General Test Procedures

The literature search indicated that the oxidants with the highest potential success were ozone, hydrogen peroxide, and chlorine. During the laboratory investigation phase the above mentioned oxidants as well as various oxidant combinations were evaluated.

Samples of seven separate combined sewer overflows from the demonstration site at Hawley Road were collected during the Fall of 1967. These samples were analyzed in the laboratory within twenty-four hours of their collection for BOD, COD, dissolved COD, total solids, suspended solids, volatile suspended solids, coliform density and pH. The data from these analyses has been reported and discussed in the main body of this report. Since the likelihood of getting sufficient and frequent combined overflows during the fall and winter seasons in Milwaukee is small, it was decided to freeze some combined overflow samples and use them for chemical oxidation evaluation during dry weather. Therefore, about twenty liters of combined overflow samples from three separate storms were frozen in individual containers having volumes of from 100 to 200 milliliters. The laboratory analysis of the three storm samples frozen for chemical oxidation studies is shown in Table A-1. During dry periods, samples were thawed as needed. Samples were mixed thoroughly in a Waring blender after thawing to provide a colloidal system characteristic of the original unfrozen raw sample. Whenever a sample without the particulate matter was needed for oxidation of the dissolved organic matter, the thawed sample was not mixed. Instead, the supernatant was filtered through an SS-597 filter paper and millipore filter discs to obtain a dissolved sample. Standard Methods (A35) procedures were employed for various analyses in the laboratory and are discussed in Appendix C.

Special Test Procedures with Various Chemical Oxidants

Chlorine and hydrogen peroxide oxidations were performed with and without ultraviolet (UV) light. Chlorine was applied in the form of calcium hypochlorite solution (HTH) and a 0.75% stock solution was utilized for hydrogen peroxide oxidation. Procedures for determination of oxidant dosages and residuals are discussed in Appendix C. Cobalt in the form of $CoCl_2 \cdot 6\ H_2O$ was utilized in a number of tests to determine if it helped to catalyze oxidation reactions of H_2O_2 and chlorine. The apparatus consisted of an eight inch diameter flat bottomed dish on a magnetic stirrer under a protective hood cover. A 300 ml aliquot of raw waste was used. For tests performed with ultraviolet light, the UV lamp was suspended above the water surface with ring stands at three and six inch heights. The two UV lamps utilized were a single bulb Sperti sunlamp and a double bulb G.E. germicidal lamp. Samples were taken at various intervals during the oxidation period for COD analysis.

Some difficulty was encountered in measuring the COD after oxidation with various oxidants. Contrary to expectations, some samples exhibited an increase in COD after oxidation. This observation could have been caused by the break

Table A-1. LABORATORY ANALYSIS OF COMBINED SEWER SAMPLES UTILIZED FOR CHEMICAL OXIDATION STUDY

Date	pH	Total solids, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	COD, mg/l	Dissolved COD, mg/l	BOD, mg/l	Coliforms, per ml
11/25/67	7.4	649	138	--	159	--	59	4260
12/07/67	6.6	---	232	113	298	50	--	2151
01/29/68	7.1	---	2158	--	1410	60	--	5730

down of organic material which prior to oxidation was not measured by the COD tests. The increase may also have been caused by the excess oxidant remaining (the reaction kinetics were not known and exact amounts of oxidants could not be utilized). Since it was desirable to know if the COD was increasing due to partial oxidation, the excess oxidants were removed prior to analyzing for COD. Several trial and error procedures were investigated for the removal of these excess oxidants. It was planned that excess oxidant would be removed after oxidation tests by adding a small excess of sodium sulfite. After the addition of sodium sulfite, the sample was aerated until a galvanic cell oxygen analyzer indicated the presence of dissolved oxygen in the sample. Also, investigations were undertaken to study the effect of excess oxidants and chemicals on the COD test results. Theoretically, the reaction between, hydrogen peroxide and hexavalent chromium in a COD test may proceed as follows:

$3H_2O_2 + K_2Cr_2O7 + 8H^+ = 3O_2 + 2Cr^{+3} + 7H_2O_2 + 2K^+$ [ORP = +0.65]. . . . EQ I

Then 1 mg H_2O_2 = 0.47 mg COD

Similarly, the reaction between sodium sulfite and dichromate may proceed as follows:

$3Na_2SO_3 + K_2Cr_2O_7 + 8H^+ = 3Na_2SO_4 + 2Cr^{+3} + 4H_2O + 2K^+$ . . . . . EQ II

Then 1 mg Na_2SO_3 = 0.127 mg/COD

Experimentally it was found that the COD exerted by hydrogen peroxide solution decreased with increasing strength of H_2O_2 solution as follows:

Concentration of H_2O_2 Solution	Ratio of mg COD/mg H_2O_2
50	0.42
100	0.41
150	0.39
200	0.38
250	0.37

The reason for such observation can be attributed to the redox relationships of hydrogen peroxide, since H_2O_2 can also react with the trivalent chromium produced as follows:

$3H_2O_2 + 2Cr^{+3} + 6H^+ + 7H_2O = 6H_2O + Cr_2O_7^{=} + 14H^+$ [ORP = +.44] . . . . EQ III

Thus hydrogen peroxide solution was found to exert a significant COD value and this was a factor in the increased COD results of hydrogen peroxide treated samples.

Also, sodium sulfite was experimentally found to have a chemical oxygen demand of 0.09 mg per mg of Na_2SO_3. This is approximately 70% of the theoretically calculated value of 0.127 and is not significant in light of the small amounts of sodium sulfite utilized in these studies.

When calcium hypochlorite was used as an oxidant, the sulfite was added in increments until a spot test with ortho-tolidine indicated that there was no more free chlorine. The sample was then aerated until a galvanic cell oxygen analyzer indicated the presence of dissolved oxygen in the sample. Experimentally it had been found that a 715 mg/l calcium hypochlorite solution exerted a nominal COD of 9 mg/l which could possibly be the result of experimental errors. This experimental observation is also supported by possible theoretical reaction between chlorine and hexavalent chromium, as:

$$3Cl_2 + 5Cr_2O_7^{=} + 34H^{+} = 6ClO_3^{-} + 10Cr^{+3} + 17H_2O \quad [ORP = -.14]. \ . \ . \ .EQ\ IV$$

The negative oxidation-reduction potential indicates that the above reaction should proceed to the left and therefore, theoretically the reaction should not take place. This leads to the conclusion that no COD should be exerted by the chlorine solution.

Somewhat contradictory results were obtained when COD tests were performed on samples from stormwater oxidation tests, whereas the COD of calcium hypochlorite solution was negligible and the COD of oxidized sodium sulfite was very small, in most cases the COD values of chlorinated waste samples which were dechlorinated with sodium sulfite and aerated were 5 to 35% higher than the samples which were not dechlorinated. Because of this difference, an alternate method of dechlorination was also used: the sample was acidified to a pH of one and stripped of chlorine by aeration. Unfortunately, the stripping process was extremely slow, often requiring several hours. In some cases, not all the chlorine was removed by the time the COD analyses were performed. In general, the COD values obtained by acidification and stripping were lower than the values obtained by sulfite treatment. The exact cause of this difference in values is not known.

Ozone Oxidation System

Ozone was purchased by the bottle and used in a pressure tank system. A schematic of the apparatus utilized is shown in Figure A-3. Ozone was supplied dissolved in 'Freon 13' under high pressure in stainless steel cylinders. Since ozone has a half life of approximately three days at room temperature it was necessary to keep the ozone cylinder packed in dry ice. A three mole-percent vapor phase concentration was utilized for oxidation studies. To maintain a constant ozone concentration supply, ozone was utilized in the vapor phase. This was achieved by inverting the ozone bottle and converting the liquid ozone to vapor phase by passing it through a vaporizing coil.

Ozone was mixed with the waste at elevated pressures in the range of 40 to 80 psig. This pressure charged stream was then placed in a graduated cylinder for the required reaction time. Samples were air-stripped to remove excess

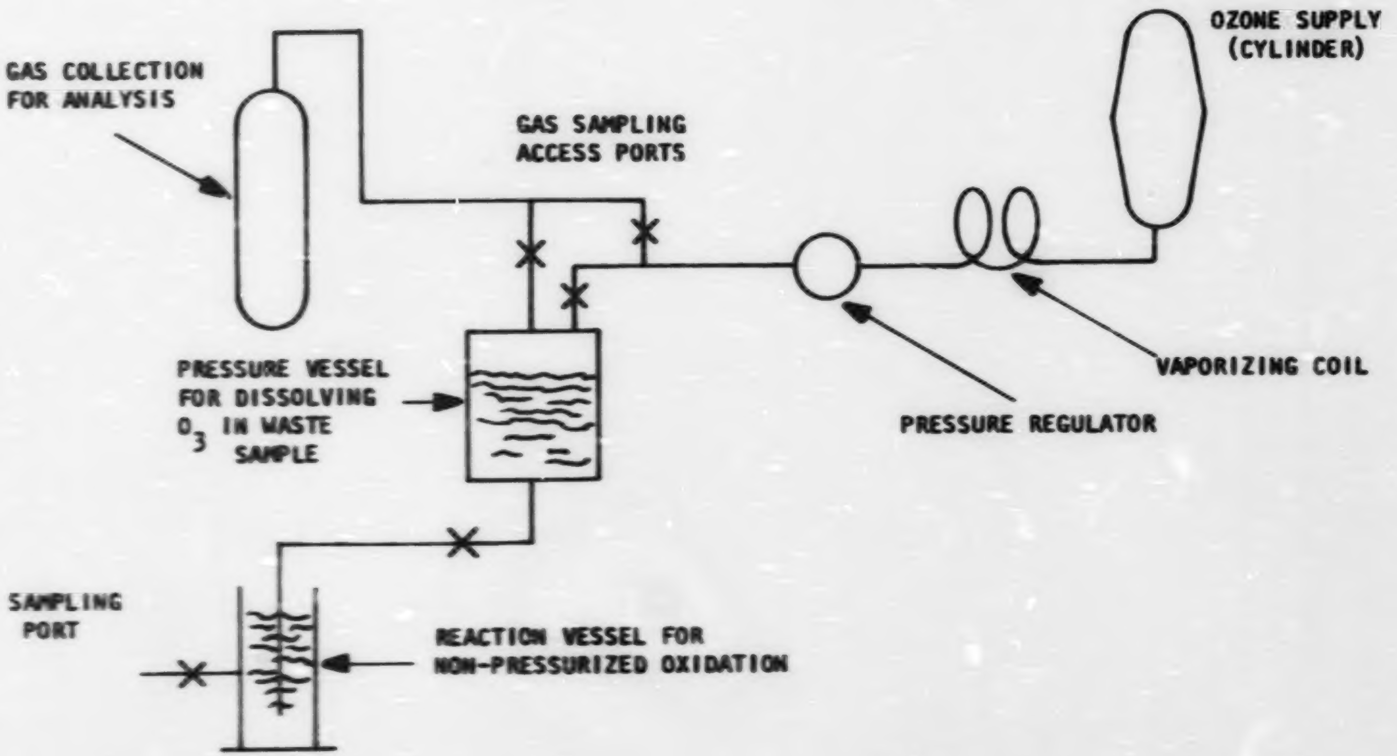

Figure A-3. Schematic of ozone test apparatus ozone remaining after the reaction time. Pressurization of waste could be total or partial. When the entire waste was pressurized, it was called total pressurization. If only a portion of the waste was pressurized, the amount was calculated as a percentage of the nonpressurized portion, and was called a recycle system. Use of a pressure tank system enabled large amounts of ozone to be dissolved and when the pressure was released the extremely small air-ozone bubbles stayed in contact with the liquid much longer than the coarse bubbles produced from diffuser type systems. Such a system was utilized because the literature search indicated that the ozone contact time is critical and greatly affects efficient use of ozone. Titrations for ozone determination were performed in accordance with Standard Methods (A35).

RESULTS AND DISCUSSION

Oxidation with Hydrogen Peroxide

Results of chemical oxidation with hydrogen peroxide are presented in Tables A-2 and A-3. Hydrogen peroxide requires a catalyst to oxidize effectively within reaction times of one hour or less. Table A-2 shows the results of the tests performed using iron as a catalyst. Oxidation tests were run on the dissolved fraction of the overflow (Tests 1 through 7) as well as the overflow after screening through a 50 mesh screen (Tests 8 and 9).

Tests 1 through 7 (Table A-2) indicated that a substantial portion of the dissolved COD can be oxidized in 15 minutes and the oxidation efficiencies were in the range of those reported in the literature. When the effluent from the 50 mesh screen (Tests 8 and 9) was oxidized with the hydrogen peroxide - iron salt system, the oxidation efficiencies were lower than those obtained when oxidizing only dissolved COD. This indicated the importance of removing a major portion of the solids prior to oxidation, since particulate matter is more difficult to oxidize than dissolved organic matter.

Use of hydrogen peroxide-iron salt system does not appear feasible. Ferrous iron seems to work well, but relatively large concentrations are required (on the order of 60 to 100 mg/l as Fe^{++}). This system requires strict pH control (3 to 4) and a neutralization and settling period to remove the iron precipitate which is formed. Organic removal efficiencies are in the 30 to 50% range for dissolved organics and were reduced to about 14% when particulate organics were present. In an attempt to more efficiently utilize the hydrogen peroxide, other catalysts were evaluated which would not be as restrictive as ferrous salts.

The literature indicated that hydrogen peroxide is decomposed by ultraviolet light. Also Test 7 (Table A-2) indicated that cobalt may help catalyze a hydrogen peroxide system. Therefore, tests were run with both these catalysts to study any improvements in the efficiency of hydrogen peroxide oxidation system. The results of these tests are shown in Table A-3. It is seen that the use of either or both cobalt and ultraviolet light along with hydrogen peroxide did not produce consistent results. From Tests 1 and 2 (Table A-3)

Table A-2. RESULTS OF CHEMICAL OXIDATION OF COMBINED SEWER OVERFLOW WITH HYDROGEN PEROXIDE

Test no.	Available O_2	COD Initial	COD Final	Percent reduction	Oxidation efficiency, %	Filtered prior to analysis
1	50	54	50	7	8	No
2	100	67	30	55	37	Yes
3	100	54	41	24	13	No
4	100	54	33	39	21	Yes
5	100	65	37	43	28	Yes
6[a]	100	65	42	35	23	Yes
7[b]	100	65	31	52	34	Yes
8	150	216	186	14	20	No
9	300	216	185	14	10	No

a. Aerated during the oxidation
b. Cobalt added during the oxidation

Notes:
1. In Tests 1 through 7 only the dissolved COD was oxidized, i.e., all solids removed prior to oxidation. Tests 8 and 9 were run on combined overflow after screening through a 50 mesh screen.
2. All oxidations were for 15 minutes at room temperature.

Table A-3. EFFECT OF UV LIGHT AND COBALT ON HYDROGEN PEROXIDE OXIDATION

Test no.	Type of sample	H_2O_2 Dosage, mg/l as O_2	H_2O_2 Remaining after oxidation, mg/l as O_2	Catalyst used	Reaction time	COD, mg/l Influent	COD, mg/l After oxidation	% COD reduction
1	Filtered	110	--	None	15	92	62	33.0
					30		75	19.0
					90		175	--
2	Filtered	110	--	UV Light[a]	15	92	149	--
					30		161	--
					90		138	--
3	Filtered	110	29	UV Light & 10 mg/l Cobalt	30	106	100	5.6
4	Filtered	110	15	UV Light & 100 mg/l Cobalt	30	106	98	7.5
5	Filtered	110	66	10 mg/l Cobalt	30	106	119	--
6	Filtered	110	54	100 mg/l Cobalt	30	106	114	--
7	Filtered	110	60	UV Light	30	58	34	41.0
8	Filtered	110	62	UV Light	30	58	39	33.0
9	Distilled water	110	93	UV Light	30	--	80	--
10	Distilled water	110	106	UV Light & 5 mg/l Cobalt	30	--	81	--
11	Filtered	110	78	UV Light	15	114	76	34.0
12	Filtered	110	66	UV Light	30	114	107	6.0
13	Filtered	110	79	UV Light	15	112	59	47.0
14	Filtered	110	68	UV Light	30	112	80	29.0

a. Ultra-violet light wave length 2800 to 3200 Å.

it is clear that reaction time has an important bearing on COD reductions in the treatment of storm waters with hydrogen peroxide. In Test 1, when a hydrogen peroxide dosage of 110 mg/l as O_2 was utilized, a 33% reduction in COD was obtained in 15 minutes; the COD reduction reduced to 19% in 30 minutes and even became negative at the end of the 90 minute reaction time. A possible explanation for the increase in COD in a certain initial reaction time may be the partial oxidation of large molecular weight organic compounds in the raw storm samples to smaller intermediate compounds which exhibited an increase in COD. Increased oxidation at a higher reaction time may then cause a decrease in COD of these samples, apparently, due to the oxidation of some of the organic carbon to CO_2 and H_2O. Similar explanations have been mentioned in literature for ozone oxidation (A18). When UV light was used as a catalyst, results were contradictory as shown in Tests 2, 7, 11, 12, 13 and 14 (Table A-3). Test 2 showed negative COD reductions for all reaction times between 15 to 90 minutes while Tests 7 and 11 to 14 showed COD reduction between 6 to 47% for reaction times of 15 and 30 minutes. Similar contradictions in results were shown when cobalt was used as a catalyst either independently or in combination with UV light (Tests 3 to 6, Table A-3).

The results presented in Tables A-2 and A-3 clearly indicated that a hydrogen peroxide reaction system was not technically feasible for treating combined sewer overflows. Thus work on such a system was abandoned.

Oxidation with Chlorine

Results of chlorine oxidation with and without ultraviolet light are presented in Tables A-4 and A-5. Oxidation with chlorine and no ultraviolet light resulted in a reduction of COD of about 20 to 25% at available chlorine dosages of 280 to 560 mg/l (Table A-4). The amount of chlorine destroyed was about 25% and hence a large chlorine residual remained after the oxidation. Reducing the chlorine dosage to 56 mg/l, reduced the percent COD oxidized to only 8% (Test 3, Table A-4). These results indicate that chlorine is not an effective oxidant for combined sewer overflows. This conclusion is supported by the literature search.

Oxidation with chlorine and ultraviolet light in the 2800 to 3200 Å range was not significantly different from those oxidations where ultraviolet light was not used (Table A-4). The reason for these low oxidation efficiencies may have been due to the long wave length light which was used i.e. 2800 to 3200 Å or the low ultraviolet output of the lamp which was used for the reactions. A review of the research conducted by Midwest Research Institute (A36) indicated that lower wave lengths were more effective. Therefore, a lower UV light wave length of 2587 Å was used for further experiments. This wave length would also provide good disinfection. The results of these experiments are shown in Table A-5. It should be noted that for light catalyzed oxidations to be effective, relatively clear solutions were required. Therefore, the results of the screening step could have a pronounced influence on the efficiency of light catalyzed oxidations.

From the results shown in Table A-5, it is seen that COD reductions of 10% to

Table A-4. CHLORINE OXIDATION TESTS[a]

Test no.	Chlorine concentration, mg/l	Reaction time, min	COD mg/l			% COD reduction		Chlorine remaining	
				After oxidation					
			Raw	W/UV	No light	W/UV[c]	No UV	W/UV	No UV
1[b]	280	15	65	---	51	---	21	---	
2	560	15	259	211	194	19	25	---	
3	56	15	177	167	163	6	8	---	
4	276	15	198	169	164	15	17	160	202
5	284	15	205	151	161	26	21	145	216

a. $Ca(OCl)_2$ used as source of chlorine.
b. Sample filtered prior to oxidation.
c. Ultraviolet wave length 2800 to 3200 Å.

Table A-5. LIGHT CATALYZED CHLORINE OXIDATION

Date 1969	Type of sample	Reaction time, min	COD mg/l Influent	COD mg/l After oxidation	Percent COD reduction	Chlorine dosage, mg/l	Chlorine remaining, mg/l	U.V. light intensity, watts[a]	Chloride conc., mg/l	Cl/COD ratio[b]
2/2	Filtered	15	105	94	11	280	115	2.9	---	15
2/2	Filtered	30	105	86	18	280	70	2.9	---	11
2/2	Filtered	60	105	77	27	280	42	2.9	---	8.5
2/2	Filtered	15	105	91	13	280	185	0	---	6.0
2/2	Filtered	30	105	89	15	280	182	0	---	6.1
2/2	Filtered	60	105	96	9	280	182	0	---	10.9
2/8	Filtered	15	71	43	39	600	401	2.9	---	7.1
2/8	Filtered	30	71	44	38	600	309	2.9	---	10.8
2/8	Filtered	60	71	37	48	600	204	2.9	---	11.6
2/9	Raw	15	147	121	18	600	384	2.9	45	8.3
2/9	Raw	30	147	111	25	600	283	2.9	82	8.8
2/9	Raw	60	147	102	31	600	286	2.9	253	7.0
2/13	Filtered	15	97	81	17	600	497	0	---	6.6
2/13	Filtered	30	97	77	21	600	497	0	---	5.7
2/13	Filtered	60	97	77	21	600	497	0	37	5.7
2/16	Filtered	30	108	76	30	900	576	2.9	382	10.0
2/16	Filtered	30	108	60	44	900	541	5.8	502	7.5
2/16	Raw	30	167	118	29	900	576	2.9	397	6.6
2/16	Raw	30	167	68	59	900	497	5.8	487	4.1
2/26	Filtered	30	93	72	23	300	84	5.8	352	10.3

a. UV Light wave length 2587 Å - 2.9 watts intensity (bulb output).
b. Ratio is mg Cl utilized per mg COD oxidized.

50% can be expected depending upon light intensity, chlorine dosage and reaction time. The amount of chlorine required is extremely large. Approximately 7 to 10 mg of chlorine is required per mg of COD oxidized. Hence, for a 200 mg/l COD waste, 1400 to 2000 mg/l of chlorine would be consumed. This also results in high chlorine residuals in the effluent. With the use of an ultraviolet light catalyst, organic removal does increase to the 25 to 50% level compared to 10-25% level without the catalyst, but large chlorine residuals are still present in the reactor effluent. This fact, coupled with relatively long reaction times (30 to 60 minutes) and poor light penetration when the waste is turbid appear to eliminate the possibility of using light catalyzed chlorine to oxidize combined sewer overflows.

Oxidation with Combined System of Hydrogen Peroxide and Chlorine

Results of oxidation with the combined system of hydrogen peroxide and chlorine with and without ultraviolet light catalyst are shown in Table A-6. The results of these tests were extremely discouraging as inconsistent and negative reductions in COD were observed. The importance of reaction time was again demonstrated (Tests 1 to 4, Table A-6) in the use of the combination of these oxidants for the treatment of storm wastes. These results were similar to the ones discussed earlier for oxidation by hydrogen peroxide alone. A small positive COD reduction was shown when reaction time was very small (instantaneous sample, Tests 3 and 4, Table A-6). For higher reaction times up to 60 minutes negative COD reductions were obtained. Also the use of UV light as a catalyst did not show any improvement in results (Tests 2, 3 and 4 compared to 1, Table A-6). Hence, investigations in this area were terminated.

Oxidation with Ozone

The result of the ozone oxidations are shown in Table A-7. Using total pressurization at 40 psig, Tests 1 and 2 show the difference in COD reductions for raw and filtered storm water samples. The higher COD reduction of 46% exhibited for raw waste sample (Test 2, Table A-7) was probably due to the flotation of some of the suspended matter as well as the higher solids content of the raw waste sample. When a 20% recycle system was used with the 10 mg/l dosage of polymer C-31 on raw sample (Test 4) the COD reduction was extremely high at 96%. The reason for such a high reduction was probably the flocculation of the suspended matter with the C-31 flocculant and the flotation of floc on the surface. Tests 5 and 6 (Table A-7) show the effect of reaction time of ozone at two different operating pressures of 40 and 70 psig. It was shown that COD reductions increased from 27 to 52% when the reaction time was increased from 1 to 20 minutes at 40 psig. There was no significant improvement in COD reductions when the operating pressure was increased to 70 psig. Therefore, a pressure of 40 psig was utilized for all future tests. The ozone dosage utilized for all the tests discussed above was 40 mg/l. When a 30 mg/l ozone dosage was utilized the COD reduction was 32% (Test A-7) for a reaction time of five minutes as compared to 43% COD reduction shown for 40 mg/l for corresponding conditions (Test A-5). This means that higher ozone dosages result in improved COD reductions. When ozone was applied in combination

Table A-6. OXIDATION WITH COMBINED SYSTEM OF HYDROGEN PEROXIDE AND CHLORINE

Test No.	Type of sample	Chlorine dosage, mg/l	H_2O_2 dosage, mg/l as O_2	Catalyst used	Reaction time	COD, mg/l Influent	COD, mg/l After[a] oxidation	% COD reduction
1	Filtered[b]	110	100	None	15	93	81	13.0
					30		95	---
					60		122	---
2	Filtered	110	100	UV Light[b]	15	93	115	---
					30		117	---
					60		127	
3	Filtered	110	100	UV Light	Instant	86	80	7.0
					15		104	---
					30		108	---
					45		104	---
					60		85	
4	Filtered	110	100	UV Light	Instant	86	82	4.8
					15		99	---
					30		106	---
					45		100	---
					60		113	---

a. After stripping of the excess oxidant.
b. Ultraviolet light wave length 2537A.

Table A-7. SUMMARY O_3 OXIDATION TESTS

Test no.	Type sample	Reaction time, min	Raw	After oxidation	% COD removed	Type recycle	O_3 Dissolving pressure psig	Approx. O_3 dosage, mg/l	Remarks
1	Filtered	3	74	55	26	Total	40	40	Excess O_3
2	Raw	3	1680	959	43	Total	40	--	No excess O_3
3	Filtered	3	73	49	33	Total	40	40	Excess O_3
4	Raw	3	1680	61	96	20%	40	--	10 mg/l C-31
5	Filtered	1	69	50	27	Total	40	40	Excess O_3
5	Filtered	5	69	43	38	Total	40	40	Excess O_3
5	Filtered	10	69	40	42	Total	40	40	Excess O_3
5	Filtered	20	69	33	52	Total	40	40	Excess O_3
6	Filtered	1	69	51	26	Total	70	--	Excess O_3
6	Filtered	5	69	42	39	Total	70	--	Excess O_3
6	Filtered	10	69	36	48	Total	70	--	Excess O_3
6	Filtered	20	69	31	55	Total	70	--	Excess O_3
7	Filtered	5	69	46	32	Total	40	30	Excess O_3
8	Filtered	5	69	46	33	Total	40	30	50 mg/l H_2O_2
9	Filtered	5	69	45	35	Total	40	30	50 mg/l Cl
10	Filtered	5	69	21	70	Total	40	30	50 mg/l Cl and H_2O_2
11	Filtered	8	84	61	27	Total		30	
12	Filtered	8	84	62	26	Total	40	30	5 mg/l Co added
13	Raw	8	189	92	51	Total	40	--	
14	Raw	8	189	154	19	20%	40	10	
15	Raw	8	189	114	40	Total	40	--	25 mg/l H_2O_2 & Cl
16	Raw	8	189	120	37	Total	40	36	Actual measurement
17	Raw	8	189	1414	25	20%	40	8	
18	Raw	8	189	116	39	Total	40	67	3 mg/l Ni added actual

Note: Samples collected fall of 1967 and frozen for subsequent use.

with other oxidants (such as Cl_2 and H_2O_2) or catalysts (such as Co and Ni) (Tests 8 through 18), no significant improvement in COD reductions could be obtained in most cases either with dissolved or raw storm water samples. However, in one case where ozone was used with both chlorine and hydrogen peroxide (Test 10), the COD reductions were observed to be significantly improved at 70%. However, this efficiency was only for the dissolved organic fraction and would be reduced significantly if particulate organic materials are present. The use of all three oxidants at their respective dosages (Test 10, Table A-7) would result in extremely high (>$1.00/1000 gal.) operating costs.

Two benefits which are possible when using a pressure tank system are the possibility of floating some of the lighter organic solids, and the probability that the heavier grit particles will settle. These benefits can greatly increase the removal efficiencies of the treatment system. From the results shown in Table A-7, ozone appears to be the best oxidant among the ones evaluated in this study because it:

1. Provides the best oxidation.
2. Requires reasonable reaction time.
3. Can be used in a pressure system allowing effective introduction of ozone.

It should be noted that all the tests shown in Table A-7 were obtained with overflow samples which had earlier been collected and frozen. Therefore, it was not possible to run disinfection tests because of the adverse effect that freezing has on the coliform organisms. Hence, further experiments were planned to study disinfection efficiency and BOD and COD removals using ozone treatment and fresh overflows.

The results of these experiments are shown in Tables A-8 and A-9. A recycle system was utilized and a value of 10% recycle was used to keep the ozone dosage in 10 to 40 mg/l range on all overflows except the April 3 overflow (Tables A-8 and A-9). Since some flotation and/or sedimentation occurs, air flotation tests were run as a control to determine how much removal was due to oxidation and how much to sedimentation and/or flotation.

Comparing the suspended solids removals (Table A-8) indicates little difference between ozone treatment and air flotation. This points out that little if any particulate matter is oxidized. These results are consistent with the oxidation results obtained with the frozen overflows. The BOD removal was generally better with the ozone treatment compared to air flotation (Table A-8). The COD removals, however, followed the opposite trend. Overall removal rates with screening and ozone treatment or flotation are in the range of 50 to 80% for the first flushes and 45-65% for the normal overflows providing means are available to remove settled and floated solids.

The amount of disinfection obtained with ozone and chlorine is shown in Table A-9. At relatively high ozone dosages good disinfection is obtained. When the dosage is dropped below 10 mg/l disinfection becomes very poor. Chlorine, however, will give good disinfection at a 10 mg/l dosage over a wide range of coliform concentrations. These results indicate that ozone may not be satis-

Table A-8. SUMMARY O_3 OXIDATION AND AIR FLOTATION TESTS (mg/l)

Date	Type[a]	SS after screening	SS after oxidation	SS after air flotation	BOD after screening	BOD after oxidation	BOD after air flotation	COD after screening	COD after oxidation	COD air flotation
4/3	FF	707	279	---	148	85	---	559	---	---
4/3	EO	183	114	---	33	12	---	121	---	---
4/17	EO	207	106	73	33	17	21	134	79	69
4/20	EO	67	48	55	13	10	10	51	36	44
4/23	EO	122	86	65	21	20	12	99	83	64
4/28	FF	331	102	65	92	36	42	331	159	119
4/28	EO	177	109	61	58	27	27	199	143	93

[a] FF - First flush
EO - Extended overflow

Table A-9. SUMMARY DISINFECTION DATA - ALL SPRING STORMS

Date	Type[a]	E. Coli, per ml	O_3 dosage, mg/l	E. Coli in effluent, per ml	Cl dosage, mg/l	E. Coli in effluent, per ml
4/3	FF	1388	80	21	--	--
4/3	EO	421	59	4	--	--
4/17	EO	1280	40	74	10	0.5
4/20	EO	1850	~30	17	10	1
4/23	EO	6000	<10	3200	10	2
4/28	FF	32000	<10	9500	10	20
4/28	EO	26000	<10	13700	10	8

a. FF - First flush
EO - Extended overflow

factory for disinfection because of its high costs and nonattainment of residual ozone for a sufficient period.

Oxidation with Gamma Radiation

Use of gamma radiation for oxidizing organics was indicated in the literature (A38)(A39). Tests were run on gamma irradiation of combined overflow using a cobalt source. The results of preliminary tests on these were discouraging and investigations into this area were terminated.

SUMMARY AND CONCLUSIONS

Table A-10 presents a summary of the various oxidants and oxidation systems utilized. Hydrogen peroxide, chlorine, and ozone were evaluated both alone and in combination. Various catalysts were also utilized including ferrous iron, nickel and cobalt. The best system was a mixture of all three oxidants, which provided up to 70% oxidation of the dissolved fraction of a combined sewer overflow. Any single oxidant did not produce greater than 50% oxidation of the dissolved fraction. When screened overflow was utilized, the highest oxidation percentage was 40%, hence particulate matter was oxidized only to a very limited extent. This indicates that an efficient solids/liquid separation system must be utilized prior to chemical oxidation. Even if this is done, a removal efficiency of only about 40% in the chemical oxidation stage could be economically realized. Therefore chemical oxidation of combined sewer overflows does not appear to be justified.

The following conclusions can be made based on the chemical oxidation studies performed.

1. Chemical oxidation of combined sewer overflow is not technically feasible.
2. Ozone was the best oxidant evaluated in this study.
3. Oxidation with chlorine requires extremely high concentrations of chlorine and results in a high chlorine residual in the effluent.
4. Particulate matter is extremely difficult to oxidize.
5. A combination of oxidants can provide increased oxidation of organic material.

Table A-10. SUMMARY OF OXIDATION OF COMBINED OVERFLOWS WITH VARIOUS OXIDANTS AND COMBINATIONS

Line no.	Oxidant	Required concentration mg/mg[a]	Contact times, min	Catalyst used	Residual oxidant remaining, mg/l	Type of organics	COD removal, %	Other limiting criteria
1	H_2O_2	3-5	15	Fe^{++}	Small	Dissolved	30-50	Requires pH in 3-4 range and removal of iron floc formed during reaction.
2	H_2O_2	5-10	15	Fe^{++}	Large	W/solids	14	
3	Cl	17-20	15-60	None	180	Dissolved	10-15	
4	Cl	30	15-60	None	500	Dissolved	20	Requires extremely high chlorine dosages and hence a dechlorinations step would be required.
5	Cl	17	15	UV Light	400	Dissolved	40	
6	Cl	17	15-30	UV Light	300	W/solids	25-30	
7	O_3	1.2[b]	5	None	Trace	Dissolved	40	
8	O_3	1.2[b]	5	None	None	W/solids	30-40	O_3 equipment requires extremely high capital equipment costs at these dosages.
9	H_2O_2 Cl & O_3	1.0 1.0 0.6	5	None	Small	Dissolved W/solids	50-70 40	
10	O_3	1.1	8	3 mg/l Ni	Small	Dissolved	40	
11	H_2O_2 & Cl	30[c]	60	None	Large	Dissolved	7-10	

a. Milligrams oxidant per mg COD oxidized to obtain stated efficiencies.
b. O_3 dosages are approximate.
c. Equal amounts of Cl and H_2O_2.

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APPENDIX B

BENCH SCALE STUDIES FOR THE UPGRADING OF FLOTATION TREATED COMBINED SEWER OVERFLOWS

INTRODUCTION

The problem of combined sewer overflows (CSO) has been recognized as a significant pollutional problem in recent years (B1). Several programs have been initiated by the federal and state governments to develop methods of coping with this problem. Among the various projects undertaken by the Environmental Protection Agency (EPA), a research and development contract was awarded to the Environmental Sciences Division of Envirex Inc. (A Rexnord Company - previously, Rex Chainbelt Inc.) to develop an effective and economical method of treatment for combined sewer overflows. Subsequently, a 5 mgd demonstration test facility was designed and installed by Envirex at the Hawley Road CSO outfall in Milwaukee utilizing the unit processes of screening and dissolved-air flotation (B2). The treatment system was operated successfully on 55 combined sewer overflows during 1969 and 1970. It was concluded that screening/flotation is an effective method of reducing pollution caused by combined sewer overflows. The overall pollutant removals measured in terms of suspended solids, volatile suspended solids, BOD and COD ranged between 60-75%. However, this performance of the demonstration system did not meet the proposed requirements of the Wisconsin Department of Natural Resources with regard to the removals of BOD and suspended solids for intermittently operated treatment facilities in the Milwaukee River Drainage Basin. These requirements called for a minimum removal of 80% of the raw BOD and suspended solids and were similar to the "secondary treatment" requirements for the physically-chemically treated wastewaters.

A proposal was prepared by the Environmental Sciences Division of Envirex Inc. to the Wisconsin Department of Natural Resources to supplement the existing evaluation program to include laboratory bench scale investigations to upgrade the quality of the effluent from the screening/flotation process. The objectives of the proposed evaluatory work were:

1. To determine the technical and economic feasibility of upgrading the quality of the effluent from the screening/dissolved-air flotation process to a level comparable to that produced by secondary treatment as interpreted by the Wisconsin Department of Natural Resources.
2. To supplement the programmed analytical determinations to include provisions for determining the total phosphorus content of pertinent field and bench scale test samples.

Scope of Work

It was anticipated that the unit treatment processes having potential for accomplishing the desired results were: 1) high-rate filtration, 2) microscreening, 3) powdered activated carbon treatment in conjunction with dissolved-air flotation (both in split flow and effluent recycle modes) and, 4) ozone oxidation. Initially, the intent of the program was to investigate the application of these processes on the effluents obtained from the field operation of the screening/flotation facility at Hawley Road. Since the 1971 operating season did not provide a sufficient number of rainfall events to complete the contract requirements, the cooperative research agreement was extended into the 1972 operational season. The conduct of the originally conceived program however, was contingent upon the anticipated continuation of the EPA Contract 14-12-40, which, at that time, expired on March 31, 1972. However, the renewal of Contract 14-12-40 could not be authorized in time for operations during 1972. A proposal was then made to the Wisconsin Department of Natural Resources to modify the work scope of the existing Rex-DNR program.

Under the terms of the amended contract, the work scope called for the reactivation of the Hawley Road site and the field operation of the screening/flotation system. It was anticipated that the allocated funds were sufficient to operate the treatment system on four separate overflows. Three of the four overflows were to be operated under optimum test conditions as determined by the EPA Contract 14-12-40 (B2). The effluent from these three overflows were to be subjected to the above mentioned bench scale evaluations for the upgrading of this effluent. The fourth overflow event was to investigate the use of powdered activated carbon on an actual combined sewer overflow run if the laboratory tests showed promise.

A review of the test data was made at the end of the three overflow events by the personnel of the Wisconsin Department of Natural Resources and Envirex Inc. It was mutually decided that the remaining funds in the contract (after allocations for shutdown of the site and writing of the final report) be utilized to conduct additional bench scale effluent recycle flotation tests involving the use of alum, polyelectrolyte and activated carbon on a selected overflow that may be more polluted than normal. It was also decided that no additional field flotation, filtration, microscreening and ozone oxidation tests be conducted on the last overflow sample.

Test Procedures

The field operation of the demonstration system was in accordance with the optimum treatment conditions determined by previous work performed under EPA Contract 14-12-40. A description of the Hawley Road site, and the design and operation details of the treatment system have been previously described and discussed in the main body of this report (Sections V and VI). A process schematic of the treatment system utilized is shown in Figure B-1.

A listing of the optimum operational conditions utilized for the field operation of the screening/flotation system, as determined previous work performed in EPA Contract 14-12-40 is as follows (B2):

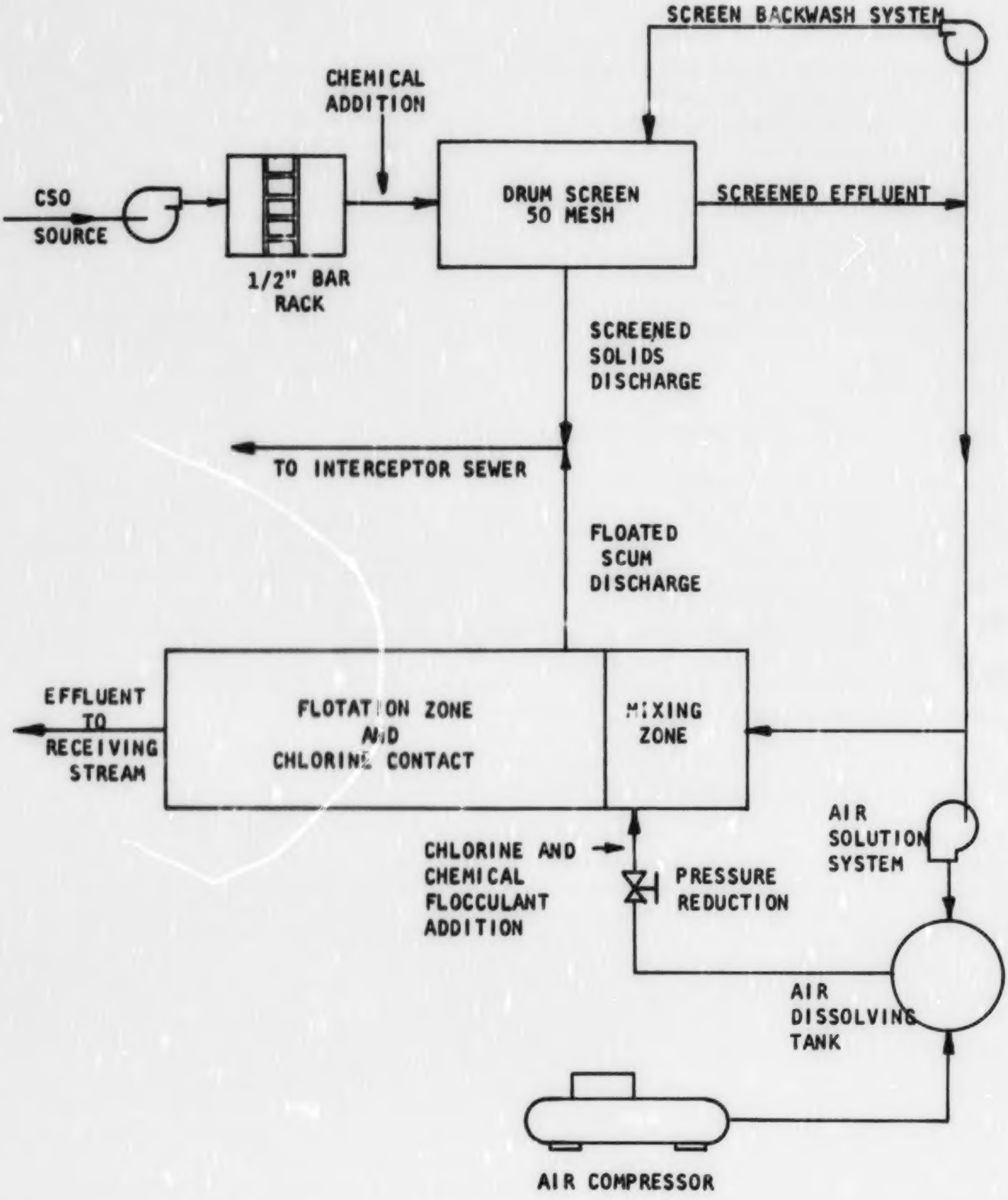


Figure B-1. Screening/flotation flow diagram

Screening

Hydraulic throughput rate	40 - 50 gpm/sq ft
Drum rotation speed	4 - 5 rpm
Maximum available headloss	12 - 14 in. water
Submergence	50 - 63%

Dissolved-air flotation (DAF)

Pressurized flow	20% raw flow
Operation pressure	50 psi
Overflow rate	3.3 gpm/sq ft
Chemical dosages	20 mg/l $FeCl_3$ 4 mg/l cationic polyelectrolyte (C-31)

Composite samples of the effluent were collected from the field operation of the screening/flotation system via an automatic sampling system which composited the samples every five minutes throughout the duration of the overflow. At times, however, some grab samples or manually composited samples were also collected whenever a large amount of sample was required for evaluations such as high rate filtration. The samples were refrigerated immediately after the run. Generally, the collected samples were subjected to various bench scale and analytical evaluations at the Envirex laboratories within 0 - 15 hours depending upon the time of the occurrence of an overflow. A description of the sample analysis procedures is presented in Appendix C. A brief description of the methods and procedures utilized for the bench scale evaluations is given below:

High Rate Filtration - The filtration tests were conducted on a dual media filter consisting of 6 in gravel, 12 in sand and 18 in anthracite. A 1 inch diameter glass column was utilized for the polishing of the flotation effluents. The filtration rate utilized was 5 gpm/sq ft. The field effluent samples were kept mixed either manually or by aeration in order to feed representative influent to the filtration column. Generally, the filtration tests were conducted for a period of 4-6 hours. Composite filter effluent samples were collected at every 1/2 to 1 hour intervals and analyzed for various pertinent constituents such as BOD, suspended solids, TOC and turbidity.

Microscreening - The microscreening tests were conducted with various types of screens made of stainless steel, nylon and polyester. The microscreening test assembly consisted of a screen holder to hold a 1.75 in. diameter screen, sealed between two O-rings. A long cylindrical tube, which was threaded to fit the screen holder was placed on top of the screen to permit water heads up to 15 inches. The openings of the various screens utilized for the tests varied between 15 and 23 microns.

Carbon-Flotation Treatment - These tests were conducted to investigate the potential of utilizing powdered activated carbon in conjunction with flocculating chemicals and dissolved-air flotation for the treatment of combined sewer overflows. The objective was to evaluate the improvement in the effluent quality when activated carbon was added to the raw CSO for the adsorption of the soluble organics. Control tests (without carbon) were also conducted to compare the bench scale effluent qualities with or without the addition of carbon.

Bench scale flotation tests with and without carbon were conducted in two different modes of dissolved-air flotation. These modes of DAF are split flow pressurization and effluent recycle pressurization.

The split flow mode of pressurization is that type of DAF where a portion of the raw flow is pressurized at a suitable pressure and is mixed with air. Since the raw flow is split in two parts, this mode of DAF can be easily simulated in the laboratory tests. However, the same is not true for the effluent pressurization mode of DAF where a portion of the treated effluent is recycled and pressurized and mixed with air under pressure.

The effluent recycle mode of DAF or the effluent pressurization concept can be well simulated in the laboratory by a technique developed by Rexnord Inc. called the "Developed Recycle" technique. The procedure consists of utilizing tap water in desired proportion for initial pressurization. The pressurized flow is then mixed with the chemically flocculated raw waste and the particulate matter is floated in a 1-liter graduated cylinder. The flotation effluent obtained from this first cycle of flotation is next pressurized in a second cycle of flotation in place of the tap water. The resulting effluent from the second cycle is considered to correspond closely to the expected flotation effluent in the field via effluent pressurization.

Ozone Treatment - Ozone utilized for the laboratory tests was supplied dissolved in 'freon 13' under high pressure in stainless steel cylinders. Since ozone has a half life of approximately three days at room temperature, it was necessary to keep the ozone cylinder packed in dry ice. To maintain a constant ozone concentration supply, ozone was utilized in the vapor phase. This was achieved by inverting the ozone bottle and converting the liquid ozone to the vapor phase by passing it through a vaporizing coil. A five mole-percent vapor phase concentration was utilized for O_3 oxidation studies. A schematic of the apparatus utilized for the ozone treatment tests is shown in Figure B-2.

A gas bulb was utilized as the contact chamber between ozone and wastewater sample. The procedure utilized for the ozone oxidation tests was as follows: The gas bulb (capacity 275 ml) was filled with the wastewater sample. Next, ozone was passed into the bulb replacing a desired amount of the sample. The ozone-waste sample mixture was allowed to remain in the gas bulb for the desired reaction time. At the end of the contact time, a small volume of the mixture was taken out for TOC analysis. The remaining mixture was then treated with potassium iodide and sulfuric acid and titrated with sodium thiosulfate for ozone determination in accordance with Standard Methods (B3).

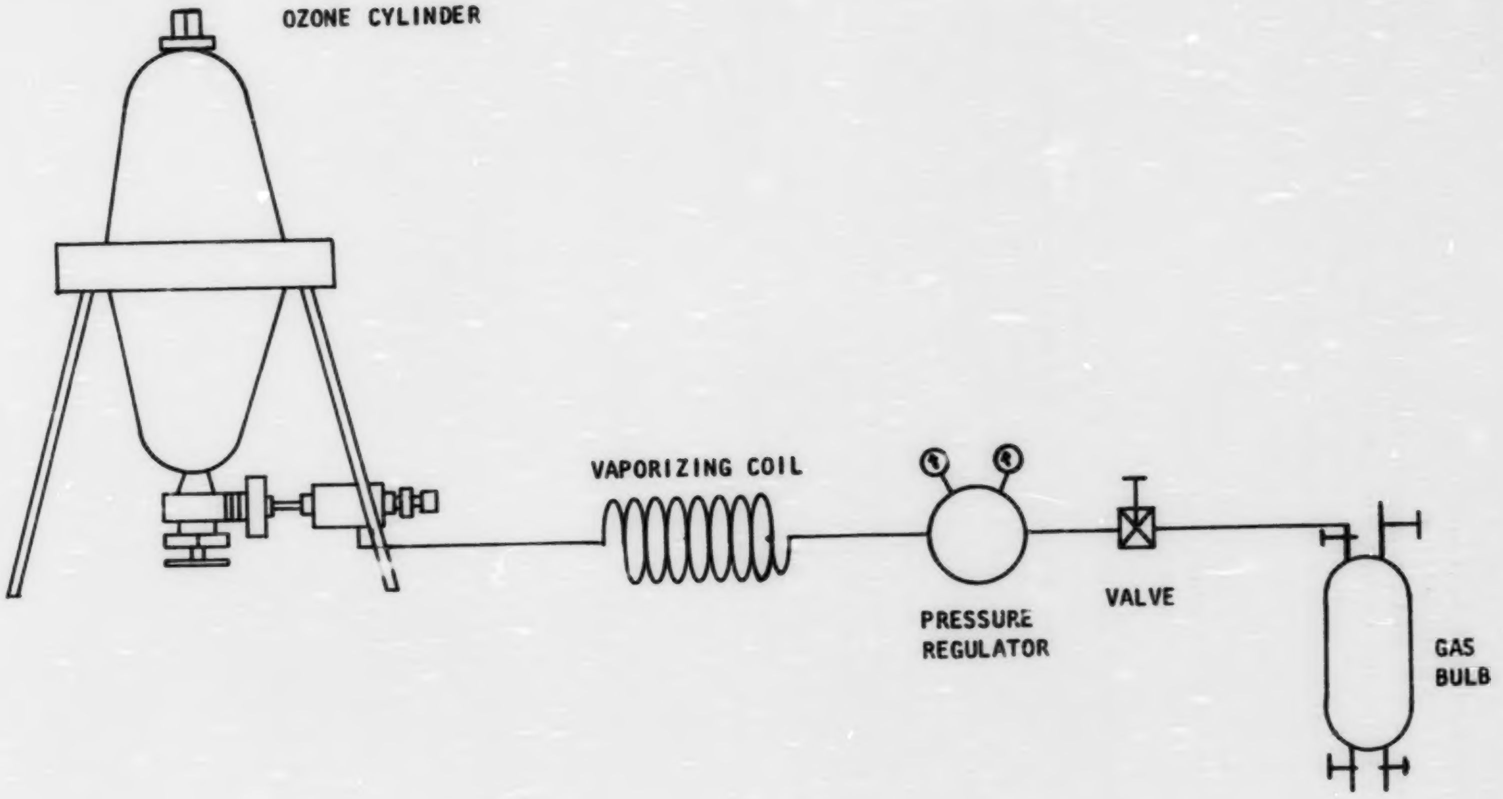


Figure B-2. Schematic of ozone test apparatus

RESULTS AND EVALUATIONS

The results of the total DNR program undertaken during the years 1971 and 1972 can be divided into two distinct areas as per the objectives, i.e.,

1. The upgrading of the field treated effluents.
2. The determination of the total phosphorus content in the raw and and flotation effluent.

The tests conducted to achieve these objectives are discussed as follows:

Operation of the Field Treatment System During 1972

The field treatment system at Hawley Road was operated on three separate overflow events during 1972. Mechanical operation of the treatment facility was excellent. The raw and flotation treated effluent qualities along with the pertinent test conditions for the three overflows are shown in Table B-1. The raw CSO analyses for the 4th overflow sample, collected for the bench flotation tests, are also included in the same table. Comparing the results shown in this table to the previous data collected at Hawley Road (Table B-2) with regard to the CSO quality, it was found that:

a. The pollutant content of the raw wastewater during these storms was significantly lower than the corresponding quality during previous seasons. For example, suspended solids for 1972 ranged between 105-181 mg/l compared to a 95% confidence value of 435 ± 129 mg/l for the 1971 season.

b. The soluble TOC/total TOC fraction during 1972 was higher than in previous years. It ranged between 0.3 - 0.6 compared to previous year's 95% confidence value of 0.32 ± 0.15.

c. The pollutant removals in the flotation effluent for most parameters ranged between 60-95% for the storms #2 and 3 and were comparable to the effluent quality during previous years. However, the removals for storm #1 were comparably lower at 35-57% but can be justified in the wake of the higher soluble organic carbon fraction (60%) in the raw wastewater for this storm.

Evaluation of Various Processes for the Upgrading of Flotation Effluents

The results of the various bench scale tests conducted on the field flotation effluents or raw samples are described in the following subsections:

1. High rate filtration
2. Microscreening
3. Flotation tests with and without activated carbon
4. Ozone oxidation

TABLE B-1.

HAWLEY ROAD FIELD DATA - 1972

Analysis	Storm #1			Storm #2			Storm #3			Storm #4
	Raw	Float Eff.	% Removal	Raw	Float Eff.	% Removal	Raw	Float Eff.	% Removal	Raw
Suspended Solids	105	53	50	160	69	57	181	36	80	157
VSS, mg/l	45	29	35	91	32	65	57	3	95	42
BOD, mg/l	21	9	57	69	27	61	49	17	65	54
TOC, mg/l	27	15	45	59	25	68	49	17	65	60
Sol. TOC, mg/l	16	12	25	32	23	28	15	16	--	30
Total Phosphate as P, mg/l	0.74	0.35	47	1.88	0.73	61	1.84	0.46	75	1.47
Total Nitrogen, mg/l	2.6	1.8	27	2.5	2.4	4	4.0	1.6	60	--

Parameter	Operating Conditions		
	Storm #1	Storm #2	Storm #3
Raw flow rate, gpm	2250	2120	2850
Overflow Rate, gpm/sq ft	2.8	2.7	3.7
Split Flow Rate, gpm	400	500	500
Operating Pressure, psi	50	50	50
Chemicals - FeCl$_3$, mg/l	25	25	25
Polymer - Nalco 607, mg/l	5.0	5.0	5.0
Duration of Overflow, minutes	52	54	72

Table B-2. SUMMARY OF RAW WATER QUALITY DATA (1969 to 1971)

	Constituent concentration at 95% confidence level		
Analysis	1971 Season[a]	1969-70 First flushes[b]	1969-70 extended overflows[a]
pH	7.2 ± 0.1	7.0 ± 0.1	7.2 ± 0.1
Total solids, mg/l	605 ± 151	861 ± 117	378 ± 46
Total volatile solids, mg/l	156 ± 73	489 ± 83	185 ± 23
Suspended solids, mg/l	435 ± 129	522 ± 150	166 ± 26
Volatile suspended solids, mg/l	146 ± 46	308 ± 83	90 ± 14
TOC, mg/l	73 ± 27	---	---
COD, mg/l	209 ± 86	581 ± 92	161 ± 19
BOD, mg/l	64 ± 32	186 ± 40	49 ± 10
Dissolved TOC/total TOC	0.36 ± 0.05	---	---
Dissolved COD/total COD	---	---	0.34 ± 0.04
Total nitrogen, mg/l	6.3 ± 1.9	17.6 ± 3.1	5.5 ± 0.8
Ortho phosphate, mg/l	0.86 ± 0.37	2.7 ± 1.0	1.0 ± 0.24
Coliform density, per ml	$75.5 \pm 69 \times 10^3$	$142 \pm 108 \times 10^3$	$62.5 \pm 27 \times 10^3$

a. Data represents 21 overflows.
b. Data represents 12 overflows.
c. Data represents 44 overflows.

High Rate Filtration - Bench scale filtration tests were performed on flotation effluents from three separate overflow events. The results of these tests are shown in Table B-3. From these results it can be seen that mixed media filtration does an excellent job in removing the particulate matter from the flotation effluents. The suspended solids removals ranged between 85 to 98+% for the bench scale test results shown in Table B-3. However, as expected, no significant reduction

Microscreening - The results of the microscreening tests on the flotation effluents for various pollutant parameters are shown in Table B-4. These tests were conducted on the field flotation effluents in both the 1971 and 1972 operational seasons.

Various screen media of 316 stainless steel, polyester and nylon were utilized for these tests in varying opening sizes between 15 to 23 microns. The weave of the polyester and nylon media was square weave type while the stainless steel media was of Dutch twill weave type. It can be seen from the results shown in Table B-4 that the percent pollutant removal on the microscreens varied over a wide range, between negative removals to greater than 90%. The reason for such a variation can be attributed to the variation in the size of the particulate matter in CSO. It can be seen from these results that consistently approximately 15 to 35 mg/l of the particulate matter passed through the microscreens and therefore is considered to be finer than 15-23 micron size. While this finer particulate matter could not be removed by the microscreens employed, it is interesting to note that similar particulate matter was removed by mixed media filtration. Also, it was indicated that twill weave stainless steel media provided somewhat better particulate removals compared to square weave plastic media but at significantly reduced throughput rates.

Flotation Tests With and Without Activated Carbon - Bench scale flotation tests were undertaken in the laboratory on raw composite CSO samples 1971-5 and 1971-6 to evaluate the effect of utilizing effluent recycle mode of pressurization as compared to split flow mode of pressurization. The results of these tests are shown in Table B-5 along with the test conditions utilized. Both these tests were conducted without the addition of activated carbon. From the results shown in Table B-5, it can be clearly seen that a significant increase in the effluent quality can be achieved via effluent pressurization as compared to the split flow pressurization. It was found that approximately 50 to 60% increase in the removals of the particulate matter could be achieved in the laboratory via pressurization of only 20% of the treated effluent instead of the raw CSO.

Also, bench scale flotation tests were conducted in conjunction with powdered activated carbon and flocculating chemicals. Pulverized filtrasorb 400 (Manufactured by Calgon Corp.) was utilized for the evaluations during storm numbers 1972-1 and 1972-2 while the powdered activated carbon grade Nuchar C-115WG (manufactured by Westvaco Corp.) was utilized during storm numbers 1972-3 and 1972-4. Initially, the chemical flocculant combination of $FeCl_3$ and a cationic polyelectrolyte (Nalco 607) was utilized for the bench scale

Table B-3. RESULTS OF THE MIXED-MEDIA FILTRATION TESTS
(Filtration rate: 5 gpm/sq ft)

Overflow no.	1972-1			1972-2			1972-3			
	TOC mg/l	S.S. mg/l	Turb. FTU	TOC mg/l	BOD mg/l	S.S. mg/l	TOC mg/l	BOD mg/l	S.S. mg/l	Turb. mg/l
Raw	27	105	--	59	69	160	49	49	181	--
Raw soluble fraction	16			32			15			
Field flotation effluent	15	53		26	16	44	14.5	16	35	25
Effluents after filtration time:										
1/2 hour	14	1	1.4	22.5	17	10	--	--	--	--
1 hour	17	2	1.6	19.5	17	6	14	11	1	3.5
2 hours	16	1	1.5	18.5	16	6	10	10	1	2.6
3 hours	17	1	1.0	16.5	13	9	--	--	--	--
4 hours	16	1	1.0	15.5	14	7	11	11	1	2.3
6 hours							16	9	1	1.3

Table 8-4. UPGRADATION OF FLOTATION EFFLUENTS BY MICROSCREENING (mg/l)

Overflow event no. and analysis	Raw waste	Float effluent from field tests	Micro-scraening effluent	Percent removals on micro-screen	Percent removals overall raw
1. 1971-3					
a. 23µ stainless steel media					
suspended solids	440	139	52	62.5	87.4
2. 1971-4					
a. 23µ stainless steel media					
suspended solids	261	131	75	42.8	71.2
3. 1971-5					
a. 23µ stainless steel media					
suspended solids	350	153	50	67.3	85.7
volatile suspended solids	127	73	37	49.4	71.0
TOC	73	36	35	2.8	52.0
b. 18µ stainless steel media					
suspended solids	350	153	36	76.4	89.9
volatile suspended solids	127	73	27	63.0	78.7
TOC	73	36	26	27.8	64.4
4. 1972-1					
a. 18µ stainless steel media					
suspended solids	105	53	2	92.4	98.0
TOC	27	15	15	0	44.4
b. 20µ polyester media					
suspended solids	105	53	21	60.4	80.0
TOC	27	15	19	-ve	29.6

Table B-4 CONTINUED
UPGRADATION OF FLOTATION EFFLUENTS BY MICROSCREENING (mg/l)

Overflow event no. and analysis	Raw waste	Float effluent from field tests	Micro-screening effluent	Percent removals	
				on micro-screen	overall raw
5. 1972-2					
a. 18μ stainless steel media					
TOC	59	25	21	16.0	64.4
b. 20μ polyester media					
suspended solids	160	69	22	68.0	85.3
TOC	59	25	23	8.0	61.0
BOD	69	27	16	40.8	76.8
c. 15μ nylon media					
suspended solids	160	69	6	91.5	96.2
TOC	59	25	24	4.0	59.4
BOD	69	27	17	37.1	75.5
6. 1972-3					
a. 20μ polyester media					
suspended solids	181	36	34	5.5	81.4
TOC	49	17	15.5	8.9	68.4
BOD	49	17	15	11.8	69.5
b. 20μ nylon media					
suspended solids	181	36	31	13.9	82.8
TOC	49	17	15	11.8	69.5
BOD	49	17	15	11.8	69.5
c. 15μ nylon media					
suspended solids	181	36	34	5.5	81.4
TOC	49	17	15	11.8	69.5
BOD	49	17	14	17.7	71.5

Table B-5. BENCH SCALE FLOTATION TESTS FOR THE EVALUATION OF EFFLUENT RECYCLE MODE OF DISSOLVED AIR FLOTATION (mg/l) (WITHOUT ACTIVATED CARBON)

Overflow no.	Field test effluent		Laboratory split flow effluent	Laboratory developed recycle effluent[a]
	High O.R.	Low O.R.[b]		
1971-5				
Suspended solids	120	153	59	18
Volatile suspended solids	68	73	31	14
TOC	38	36	40	24
Soluble TOC	18	18	21	23
1971-6				
Suspended solids	92	88	39	16
Volatile suspended solids	62	58	31	16
TOC	16	16	14	12
Soluble TOC	10	9	--	--

a. Developed recycled effluent obtained to simulate the effluent pressurization in field. The procedure consisted of using the tap water for initial pressurization in the desired proportion and then pressurizing the floated effluent for the next cycle of flotation.

b. O.R. = overflow rate

Test Conditions:

Ferric chloride dosage: 25 mg/l
Nalco 607 dosage: 5 mg/l
Pressurized flow (both for split as well as developed recycle tests): 20%
Rise rate: 1 fpm

Scum volume: 20-30 ml
Settled sludge: trace
Flocculation time: 2 minutes
Detention time: 5 minutes

evaluations since this combination was found to be suitable for the field tests at the Hawley Road site. Later, several other flocculant chemical combinations were tried as the above combination was indicated to be unsuitable. The various tests undertaken and the subsequent developments will be discussed in their respective chronological order in the following sections.

The results of the tests conducted on the raw waste from storm no. 1972-1 are shown in Table B-6. Three tests were conducted at varying contact times and carbon dosages in the split flow mode of DAF. The effluent quality obtained via these tests was considerably lower. Based on the results of these tests it was indicated that:

1. The flocculant combination of $FeCl_3$ and a cationic polyelectrolyte may not provide good flocculation in conjunction with powdered activated carbon.

2. Split flow mode of DAF may not be suitable when used in conjunction with powdered activated carbon treatment.

Several flocculant chemical combinations were investigated in 100ml graduated cylinder bench tests to find the combination that would provide suitable flocculation of the raw waste in conjunction with carbon. Various cationic, anionic and non-ionic polymers along with alum or $FeCl_3$ were evaluated. A combination of alum and Atlas 105C, a cationic polymer, was concluded to be the best flocculant chemical combination. This chemical combination along with powdered activated carbon was utilized for the DAF tests on raw CSO samples from Storm No. 1972-2. An effluent pressurization mode of DAF was utilized during these tests. The results of these tests are shown in Table B-7. It can be seen that an excellent removal of the pollutants was achieved during these tests. The TOC concentration of the effluents from the three tests was 12 mg/l as compared to a raw content of 59 mg/l. However, no appreciable improvement in the effluent quality was shown because of either an increase in the activated carbon dosage or in the contact time prior to the addition of the flocculating chemicals. It was also found that greater than 60% removal was achieved in the dissolved organic pollutants, based on the soluble TOC concentrations of the raw and effluent samples (assuming all the TOC in the effluent was in the soluble form).

It was also indicated that probably an excess of various chemicals had been utilized during these tests and that further reductions in these dosages may be possible.

The above mentioned changes were incorporated in the carbon flotation tests on Storm No. 1972-3. Also, direct comparative tests were conducted for split flow and effluent recycle modes of DAF for the various test conditions evaluated during the earlier storms. The results of these tests are shown in Table B-8. It was again confirmed that the effluent quality in the effluent recycle mode of DAF tests was significantly superior to the corresponding quality in the split flow mode of DAF (test Nos. 4 and 5 compared to Nos. 1 and 2 respectively). Also, it was confirmed that the flocculant combination of alum and Atlas 105C provided a better effluent quality compared to the ferric chloride

Table B-6. CARBON FLOTATION TREATMENT - STORM NO. 1972-1

Raw waste analysis:

Suspended solids, mg/l	105
TOC, mg/l	27
Soluble TOC, mg/l	16

FLOTATION TESTS

Test no.	1	2	3
Test conditions:			
Mode of DAF treatment	Split flow	Split flow	Split flow
Carbon (Filtrasorb 400) Dosage, mg/l	100	100	50
Carbon contact time prior to flocculant addition, min	0	45	60
$FeCl_3$, mg/l	25	25	25
Nalco 607, mg/l	5	5	5
Flocculation time, min	10	10	10
Flotation data:			
Split flow rate, %	20	20	20
Pressure, psi	45	45	45
Flotation time, min	5	5	5
Scum volume, gal/1000 gal.	15	35	25
Sludge volume, gal./1000 gal.	10	5	<10
Effluent quality:			
Suspended solids, mg/l	156	23	118
TOC, mg/l	72	23	56

Table B-7. CARBON FLOTATION TREATMENT - STORM NO. 1972-2

Raw waste analysis:

Suspended solids, mg/l	160
TOC, mg/l	59
BOD, mg/l	69
Soluble TOC, mg/l	32

FLOTATION TESTS

Test no.	1	2	3
Test conditions:			
Mode of DAF treatment	Effluent recycle	Effluent recycle	Effluent recycle
Carbon (Filtrasorb 400)			
Dosage, mg/l	50	100	50
Carbon contact time prior to flocculant addition, min	60	60	5
Alum, mg/l	50	50	50
Atlas 105C, mg/l	3.5	2.5	2.5
Flocculation time, min	2.5	2.5	2.5
Flotation data:			
Effluent recycle rate, %	25	25	25
Pressure, psi	45	45	45
Flotation time, min	5	5	5
Rise rate, fpm	<1	<1	1.0
Scum volume, gal./1000 gal.	20	32	15
Sludge volume, gal./1000 gal.	Trace	Trace	Trace
Effluent quality:			
Suspended solids, mg/l	8	12	11
TOC, mg/l	12	11.5	12
BOD, mg/l	5	3	5

Table B-8. CARBON FLOTATION TREATMENT - STORM NO. 1972-3

Raw waste analysis:	Suspended solids, mg/l	181
	TOC, mg/l	49
	BOD, mg/l	49
	Soluble TOC, mg/l	15

	FLOTATION TESTS						
Test no.	1	2	3	4	5	6	7
Test conditions:							
Mode of DAF treatment	Split flow	Split flow	Effluent recycle	Effluent recycle	Effluent recycle	Effluent recycle	Effluent recycle
Carbon (Nuchar 115) dosage, mg/l	0	50	0	0	50	50	100
Carbon contact time prior to flocculant addition, min	0	10	0	0	5	30	60
Alum, mg/l	40	40	25($FeCl_3$)	40	40	40	40
Atlas 105C, mg/l	1	1	5(Nalco 607)	1	1	1	1
Flocculation time, min	8	8	12	8	8	8	8
Flotation data:							
Split flow or effluent recycle, %	25	25	25	25	25	25	25
Pressure, psi	45	45	45	45	45	45	45
Flotation time, min	5	5	5	5	5	5	5
Rise rate, fpm	0.8	2.5	2.1	2.4	2.0	2.1	1.8
Scum volume, gal./1000 gal.	15	20	15	15	20	20	25
Sludge volume, gal./1000 gal.	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Effluent quality:							
Suspended solids, mg/l	14	15	10	4	3	1	2
TOC, mg/l	11.5	11.5	13	10	8.5	6.5	9.5
BOD, mg/l	9	8	7	6	5	4	4
Turbidity, FTU	8.5	7.7	6.3	3.3	2.5	2.0	2.2

and Nalco 607 combination (test No. 4 compared to No. 3). The results shown in test Nos. 4 to 7 again indicated that the effect of increased carbon contact time prior to flocculation was insignificant. A carbon dosage of 50 mg/l at minimum carbon contact time was considered to provide the optimum results with regard to the effluent quality.

However, it was also noted that the effluent quality in the effluent recycle mode of DAF without the addition of carbon (test No. 4) was quite favorable when compared to the corresponding quality with carbon (test no. 5). The addition of 50 mg/l carbon would add approximately 5¢/1000 gal. to the treatment cost of the system. Therefore additional comparative tests with and without carbon were recommended at this stage to further explore the effect of carbon addition, since the high removal of soluble organics from the raw waste without the addition of carbon are questionable. Also, it was pointed out that since alum was being utilized as a flocculant, significant removal of the total phosphorus content may be possible via the use of a suitable alum dosage. These considerations were further evaluated on an additional overflow sample (Storm No. 1972-4). The results of these tests are shown in Table B-9. The results showed some improvements in the effluent quality by increasing the alum dosage from 40 to 100 mg/l (test No. 2 compared to No. 1). The total phosphate removals exceeded 85% in all cases but were significantly better at 95% in Test No. 2 at the increased alum dosage of 100 mg/l without the use of powdered carbon. Again, the effect of the addition of 50 mg/l carbon was very marginal (test Nos. 1 and 2 compared to Nos. 3 and 4). Such high removals of soluble organics without the addition of carbon were again questioned but no additional bench scale or field tests could be conducted because of limited funds. The static nature of bench scale tests may have contributed to the high removals of soluble TOC. No firm conclusions with regard to the use of activated carbon in conjunction with flotation could be made without additional tests under dynamic field operating conditions.

Ozone Oxidation - Bench scale ozone oxidation tests were performed on 3 raw and 3 field flotation effluent samples. These samples did not correspond to the operation of the treatment system during 1972 and instead were obtained during the system operation of 1971. The tests were conducted on filtered and unfiltered samples to evaluate the oxidation of soluble and particulate organic matter. The results of these tests are shown in Table B-10. It can be seen that extremely poor oxidation of the organic matter was achieved (as measured by influent and effluent TOC concentrations) with ozone dosages as high as 30 mg/l. The reaction with ozone is expected to be instantaneous, but, no improvement in the effluent TOC values was indicated by increasing the ozone contact time. Therefore, it was concluded that ozone treatment of CSO was technically unfeasible.

Removal of Total Phosphates

Analyses of the total phosphate concentrations were conducted on the raw and flotation effluent samples for both the 1971 and 1972 operational seasons. Also, phosphorus analyses were made for the bench scale test samples of

Table B-9. CARBON FLOTATION TREATMENT - STORM NO. 1972-4

Raw waste analysis:

Suspended solids, mg/l	157
TOC, mg/l	60
BOD, mg/l	54
Total phosphate as P, mg/l	1.47
Turbidity, ftu	70
pH	7.5
Soluble TOC, mg/l	30

FLOTATION TESTS (all in effluent recycle mode)

Test no.	1	2	3	4
Test conditions:				
Carbon (Nuchar 115) Dosage, mg/l	0	0	50	50
Carbon contact time prior to flocculant addition, min.	0	0	0	0
Alum, mg/l	40	100	40	100
Atlas 105C, mg/l	0.75	0.75	0.75	0.75
Flocculation time, min.	10	10	10	10
Flotation data:				
Effluent recycle, %	25	25	25	25
Pressure, psi	45	45	45	45
Flotation time, min.	8	8	8	8
Rise rate, tpm	2.4	2.4	2.0	2.0
Scum volume, gal/1000 gal.	20	20	25	30
Sludge volume, gal/1000 gal.	Trace	Trace	Trace	Trace
Effluent quality:				
Suspended solids, mg/l	5	<1	<1	2
TOC, mg/l	15	12	13	11
BOD, mg/l	8	5	5	5
Total phosphate as P, mg/l	0.24	0.07	0.09	0.23
Turbidity, ftu	4.3	1.0	1.5	1.9
pH	7.1	6.7	7.1	6.6

Table B-10. OZONATION TESTS
(tests done at atmospheric pressure)

	Unfiltered samples		Filtered samples				
Test no.	1	2	3	4	5	6	7
Sample	Raw-1	Effluent-1	Raw-2	Effluent-2	Effluent-2	Effluent-3	Effluent-3
Ozone dosage, mg/l	30	30	31	31	31	31	31
Contact time,^{a} min	5	5	5	5	10	5	5
Air purged (10 min)	Yes	Yes	No	No	No	No	No
Initial color^b, units	--	--	30	5/10	5/10	15	5
Initial TOC, mg/l	31.5	23	17	10.5	10.5	16	14
Final color^b, units	--	--	5	--	0/5	5/10	0/5
Final TOC, mg/l	30.0	18	16.5	10.0	9.5	14	13.5
O_3 residual at end of 5 min	--	--	0.9 mg/l	--	--	--	--

a. Contact time - samples were shaken in contact with ozone. All samples were 215 ml in a 275 ml gas sampling tube. The remaining 60 cc was occupied by a gas mixture containing 5.2 mole per cent ozone.
b. A color of 5/10 means that the color was between 5 and 10 color units.

Storm No. 1972-4 as discussed earlier. The results of all these tests are shown in Table B-11. It can be seen that generally, the removal of total phosphates varied between 40 and 75% for the field flotation effluents. Significant improvement in these removals (up to 95%) were achieved, however, during the bench scale tests on Storm No. 1972-4 by the addition of alum as a flocculant as discussed earlier for carbon-flotation test results. Therefore, it is recommended that the addition of alum as a flocculant be evaluated in field flotation tests to confirm the improved removals of phosphorus on a full scale basis.

DISCUSSION

The bench scale tests conducted during this study have unquestionably demonstrated that the effluent quality currently obtained via the screening/flotation treatment of combined sewer overflows can be improved. Both microscreening and mixed media filtration can contribute towards a significant improvement of the treated effluents with regard to the particulate matter. However, neither of these unit processes can remove any of the soluble or dissolved pollutants that are present in the raw combined sewer overflows. Moreover, it has been indicated that approximately 15-35 mg/l of the particulate matter present in the flotation effluents is finer than 15-20 microns and therefore passes through the corresponding screen openings. Filtration results, however, were found to be significantly better than microscreening, as measured by the filtrate suspended solids because of the very complex mechanism of filtration, whereby the removed solids may form a mat and help to remove the remaining finer particulates.

Assuming that the particulate matter can be effectively removed via a suitable size microscreen or mixed media filtration, significant improvement in the overall removals cannot be attained without some reduction of the soluble organic pollutants. Theoretically, this could be achieved by adsorption on activated carbon or oxidation via chemical oxidants such as ozone. The results of the ozone oxidation tests were concluded to be technically unfeasible. However, it was found through the various tests conducted during the carbon-flotation experiments that a significant reduction (greater than 60%) in the soluble organics (as measured by TOC) along with an excellent removal of particulates, can be achieved via dissolved-air flotation in the effluent recycle mode of operation. The addition of powdered activated carbon provided only marginal improvement in the effluent quality. This may have been a result of the static nature of bench scale tests. The high removals of soluble organics seen in the bench scale flotation tests without carbon may not be sustained in field tests. Therefore, it is recommended that additional bench and field flotation tests in conjunction with powdered activated carbon be conducted to confirm the findings of the results of this study.

A new chemical flocculant combination consisting of alum and a cationic polymer Atlas 105C was found to provide the best results. The addition of alum also helped in providing more than 90% reduction of total phosphates. Thus, the various advantages that can be achieved through the use of effluent recycle mode of dissolved-air flotation in conjunction with alum and a cationic

Table B-11. RESULTS OF TOTAL PHOSPHATE ANALYSIS

A. Results of field operation of the flotation system.

Overflow no.	Total phosphate as P, mg/l				
		High overflow rate		Low overflow rate	
	Raw	mg/l	% removal	mg/l	% removal
1971-1	0.68	--	--	0.17	75.0
1971-2	0.19	0.13	31.5	0.10	47.5
1971-3	0.77	0.23	70.0	0.19	75.4
1971-4	1.23	1.24	--	0.80	35.0
1971-5	1.62	0.79	51.3	0.75	53.7
1971-6	0.58	0.35	39.7	0.34	41.5
1972-1	0.74	--	--	0.35	47.2
1972-2	1.88	--	--	0.73	61.1
1972-3	1.84	--	--	0.46	75.0

B. Bench scale test results for conditions shown in Table B-9.

Overflow no.	Raw	Effluent without carbon				Effluent with 50 mg/l carbon			
		Alum 40 mg/l	% removal	Alum 100 mg/l	% removal	Alum 40 mg/l	% removal	Alum 100 mg/l	% removal
1972-4	1.47	0.24	83.8	0.07	95.2	0.09	93.8	0.23	84.4

polymer are:

1. Significant improvement of the flotation treated effluents with regard to both the particulates and the soluble organic pollutants.
2. No additional unit processes are required to achieve these improvements.
3. No significant increase in the chemical costs were observed by changing to the new flocculant combination. The operating costs have been concluded to be approximately 3.1¢/1000 gal. in an earlier study (B2).
4. Significant reduction in the phosphorus content of the treated effluents.

Based on these advantages, it was recommended that the above described treatment system be utilized for the treatment of combined sewer overflows at the Hawley Road test facility to confirm the findings of the bench scale tests. It is anticipated that if the field tests are successful, the above findings can be implemented in full-scale screening/flotation systems.

It should also be noted that the above recommended modifications with regard to effluent recycling have been approved by U.S. EPA for the Hawley Road test facility. The modified treatment system will then be operated on a limited number of combined sewer overflows. The test program, however, does not include any evaluation of the powdered activated carbon-flotation concept. Therefore, it is recommended that separate field tests with powdered activated carbon be conducted to confirm the findings of the bench scale results. Such an evaluation would involve the operation of the treatment system on six or more overflow events and can be conducted under the independent sponsorship of the Wisconsin Department of Natural Resources.

SUMMARY AND CONCLUSIONS

This report documents the results of a test program undertaken to upgrade the quality of the effluent from an existing screening/flotation system in Milwaukee, Wisconsin for the treatment of combined sewer overflows. The unit treatment processes investigated to accomplish the above objective were: 1) high-rate filtration, 2) microscreening, 3) powdered activated carbon in conjunction with dissolved-air flotation (both in split flow and effluent recycle modes, and 4) ozone oxidation.

The results of the bench scale tests have demonstrated that the effluent quality currently obtained via the screening/flotation treatment of combined sewer overflows can be improved significantly. Both microscreening and mixed media filtration were found to provide high quality effluents with regard to particulate matter; with filtration treatment providing consistently higher removals than microscreening. However, neither of these processes could remove any of the soluble organics present in the raw waste. The removal of the soluble organics via ozone oxidation was not successful. However, a significant (>60%) reduction in the soluble organics was achieved along with excellent removal of particulate matter via powdered activated carbon and flotation treatment. Such treatment required the operation of dissolved-air flotation in the effluent recycle mode. Also, the use of a new flocculant combination consisting of alum and a cationic polymer (Atlas 105C) was found to be necessary for achieving the improved effluent quality via carbon addition. It was also noted that the effluent quality in the effluent recycle mode of DAF was significantly better than the split flow mode of DAF and compared favorably with that achieved with carbon addition.

The following conclusions can be made based upon the upgrading study performed:

1. The effluent quality currently obtained via the screening/flotation treatment of combined sewer overflows can be upgraded significantly.
2. Both mixed media filtration and microscreening were found to be effective means of removing the particulate matter in the flotation effluents. However, neither of these processes can remove any soluble organic fraction present in the treated effluents.
3. Approximately 20-30 mg/l of the suspended solids in the flotation effluents were finer than 15-20 micron size.
4. Filtration treatment of the flotation effluents provided better removals of the particulate matter compared to microscreening.
5. Flotation treatment of the raw CSO in the effluent recycle mode of dissolved-air flotation provided better effluent quality compared to filtration or microscreening of split flow treated flotation effluents. However, the most optimum results were achieved via a new flocculant combination of alum and Atlas 105C (polymer) as compared to the previously used $FeCl_3$ and cationic polymer combination.
6. The field test results showed a total phosphate removal of 40-75%. These removals could, however, be upgraded to greater than 90% by using the alum-polymer combination during bench scale tests.
7. Powdered activated carbon, when used in conjunction with DAF in the effluent recycle mode, provided excellent removals of both particulate and soluble organic pollutants. These removals, however, were not significantly better than the effluent quality achieved during the bench test results without the use of activated carbon.
8. Ozone treatment of CSO's did not provide any significant removal of organic pollutants.

It was recommended that the existing flotation system should be modified to an effluent recycle type of system and additional field tests should be conducted with and without the addition of powdered activated carbon.

REFERENCES - APPENDIX B

B1. Pollution of Stormwater and Overflows from Combined Sewer Systems - A Preliminary Appraisal, USPHS, November, 1964.

B2. Mason, D.G. and Gupta, M.K. "Screening/Flotation Treatment of Combined Sewer Overflows", USEPA Report No. 11020FDC-01/72, January 1972.

B3. Standard Methods for the Examination of Water and Waste Water - 13th Edition, American Public Health Association, New York, 1971.

APPENDIX C

ANALYTICAL PROCEDURES

ANALYTICAL INSTRUMENTS AND APPARATUS

pH Meter: Beckman Models H-2 and SS-2
Beckman Instruments Incorporated
Fullerton, CA

Incubator: Model 1483
Precision Scientific Co.
Chicago, IL

Conductivity Bridge: Model RC16B2
Industrial Instruments Inc.
Cedar Grove, NJ

BOD Incubator: Labline No. 3554B and No. 3555 Incubators
Lab-Line Instruments, Inc.
Melrose Park, IL

Analytical Balance: Type H5 and Type H10
Mettler Instruments Corp.
Hightstorm, NJ

Ozone Cylinder: Vaporising Coil and Regulator
Matheson Company, Inc.
East Rutherford, NJ

Spectrophotometer: Coleman Model 14
Coleman Instrument Co.
Maywood, IL

TOC Analyzer: Beckman Model 951 Total Carbon Analyzer
Beckman Instrument Co.
Fullerton, CA

ANALYTICAL PROCEDURES AND ANALYSES

The following analyses were performed according to Standard Methods for the Examination of Water & Wastewater, (SM) 12th and 13th Editions, 1965 and 1971 respectively, and Methods for Chemical Analysis of Water and Wastes (MCA), Water Quality Office, U.S. Environmental Protection Agency, 1971. The page numbers of the analytical procedures used and the references are noted with each analysis.

Solids - Total	*SM*, 13th Ed., p. 535; *MCA*, p. 280; Evaporation to dryness at 103°C.
Solids - Total Volatile	*SM*, 13th Ed., p. 292 and 536; *MCA*, p. 282; Residue and dish ignited at 500°C.
Solids - Suspended	*SM*, 12th Ed., p. 424; Filtration through asbestos mat in gooch crucible; dried at 103°C.
Solids - Volatile Suspended	*SM*, 12th Ed., p. 425; Residue and filter from the suspended solids analyses are ignited at 600°C. The filter from the suspended solids test is transferred to a tared crucible and charred before ignition.
Biochemical Oxygen Demand (BOD)	*SM*, 13th Ed., p. 489; Conventional 5 day procedure. DO measured by either YSI probe or Winkler method
Chemical Oxygen Demand (COD)	SM, 13th Ed., p. 495; *MCA*, p. 19.
Phosphate - Ortho	SM, 12th Ed., p. 231; Amino naphthol sulfonic acid (ANS) procedure.
Phosphate - Total	*MCA*, p. 242 and *SM*, 12th Ed., p. 231; Sample is digested with persulfate (*MCA* method) and phosphate measured by ANS procedure (*SM*).
Nitrogen - Kjeldahl	*SM*, 13th Ed., p. 244; *MCA*, p. 149; Digestion of sample followed by distillation and titration. Measures both organic N and NH_3.
Chloride	*SM*, 12th Ed., Method A, p. 86. A 0.423N standard silver nitrate titrant was used instead of 0.0141N because of high chloride content in raw storm H_2O, thus giving a more detailed endpoint.

Chlorine, Total Available - *SM*, 12th Ed., Method A, p. 91.

Ozone Concentration	*SM*, 12th Ed., Method A, p. 220; The titration procedure stated was followed, but the sample collection and ozone absorption techniques are those as specified by the Matheson Company (Matheson Gas Data Book).
Coliform - Bacteria Count	*SM*, 13th Ed., p. 679; Membrane filter procedure. The millipore filter technique described in "Techniques for Microbiological Analysis (ADM-40)", Millipore Filter Corp., Bedford, MA, p. 22 was used. Where necessary, samples were dechlorinated using $Na_2S_2O_3$.

Analysis for Soluble (Dissolved) Matter

The analysis for soluble matter, i.e., TOC or BOD, was obtained by filtering the sample through a millipore filter (0.45 µ and then performing the appropriate analysis on the filtrate. If the sample contained gross amounts of solids which would rapidly blind the millipore filter disc, the sample was prefiltered through SS-597 filter paper. The filtrate from this prefiltration was then filtered through the millipore disc as described above.

APPENDIX D

BENCH SCALE TEST PROCEDURES

DISSOLVED-AIR FLOTATION TEST PROCEDURE

A copy of the instructions for performing dissolved-air flotation tests is attached. This sheet described the test as normally used in the REX Chainbelt Process Laboratory. This procedure was modified at times during the chemical oxidation tests by using different detention times and by using ozone instead of normal air as the source of bubbles.

The rate of separation of the suspended solids from a waste is useful in the design of industrial waste treatment equipment. Rate of separation data may be conveniently obtained in the laboratory from treatment tests performed on the waste in question. The treatment process which will be considered are dissolved-air flotation and sedimentation. Generally, the procedure used in obtaining rate-of-separation data is to observe the solids/liquid interface and to record its travel with time.

A. Dissolved-Air Flotation

In the tests using dissolved-air flotation, the rate of rise of the major portion of the solids is recorded. At times the solids-liquid interface may be vague and good judgment may have to be exercised in following this interface. Care should be taken to avoid following the interface formed by the air bubbles along. In general, this interface lags behind the solids-liquid interface.

A suggested procedure for the performance of laboratory flotation tests and the equipment needed is as follows:

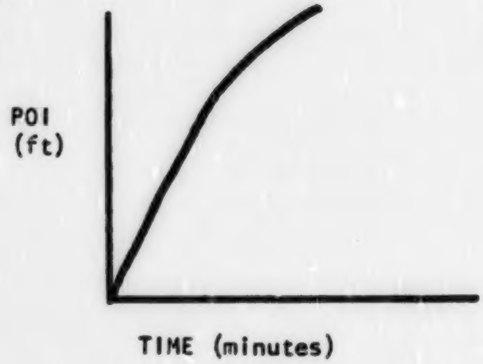
1. Equipment
    a. Flotation pressure cell
    b. Graduated cylinder of one liter capacity containing an effluent sampling arm
    c. Tire pump or source of compressed air
    d. Gooch crucibles for suspended solids determinations
    e. Stop watch
2. Flotation Test Procedure
    a. Record waste temperature, pH, operating pressure, recycle rate, and flotation detention time

b. Record rate of separation data. The form shown below is suggested in obtaining the rate of separation data.

The ultimate data desired is the position of the interface at various intervals throughout the test. The column below labeled "volume" is used as a convenient means of obtaining the position of the interface at any given time. For example, in the hypothetical case shown below, a liter graduate was used in the test. At the beginning of the test, the solids-liquid interface is at the bottom of the graduate or at zero volume. As flotation progresses, the solids-liquid interface moves progressively up the height of the graduate. The position of the interface at any given time may be conveniently obtained using the appropriate graduation mark on the liter cylinder as a reference. After the flotation test, the graduation marks may be converted to the feet of height by actual measurement.

Time (min)	Volume (ml)	POI (Position of Interface) (feet)
0	0	0
1	100	0.115
2	350	0.411
3	500	0.589
4	650	0.766
5	800	0.946
6	950	1.222
7	950	1.222
8	950	1.222

The data obtained are plotted using Time as the abscissa and POI in feet as the ordinate.



The slope of the straight line portion of the curve represents the rate of particle rise.

During flotation it should be noted whether settling of solids took place. Note observation.

c. Record the floated scum volume obtained immediately before obtaining a sample of the effluent.

d. Obtain sample of effluent five minutes after flotation is started for the appropriate analyses. Repeat the flotation and obtain another sample of effluent for analysis after an eight minute detention period.

e. If possible, a small portion of the floated scum should be analyzed for total solids content.

MICROSCREENING TEST PROCEDURE

The microscreening bench test apparatus consisted of a plexiglass vessel threaded to accept a screen media holder. A precision relieving, air regulator supplied air pressure to the liquid above the microscreening media simulating constant liquid heads of 1.5 inches to 61.5 inches of water. A sketch of the apparatus is shown in Figure D-1. The sample is poured in the inverted sample reservoir. The filter media with the microscreening material is threaded on the sample reservoir. Air pressure is applied to simulate the desired liquid head. The entire apparatus is then inverted. The sample will bubble out of the sample reservoir until the liquid covers the spout end of the reservoir. In all tests, the throughput rate through the media must be less than the flow out of the reservoir. By varying the pore size of screens, by media selection and varying the head of water pressure applied, no problem was experienced in obtaining the flow required. By measuring the volume of filtrate collected per unit time, throughput rates could be calculated. The filtrate was also analyzed for suspended solids so that removal rates could be calculated.

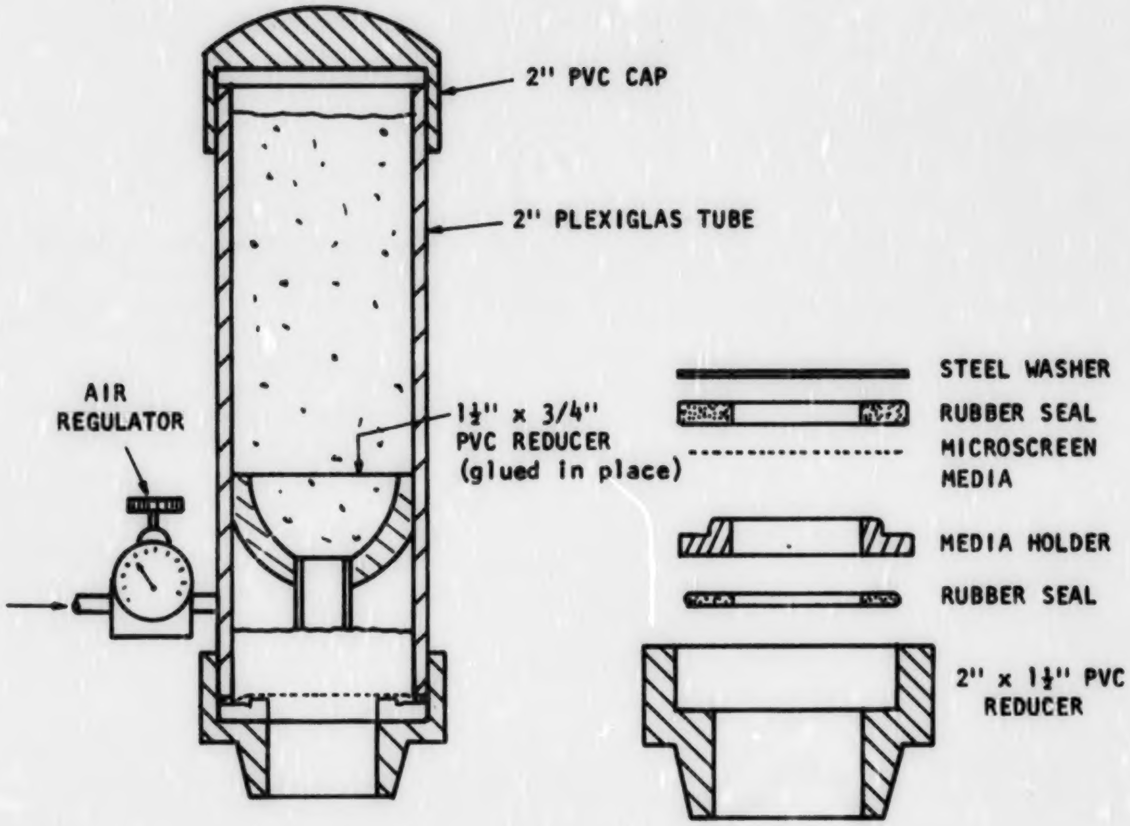


Figure D-1. Microscreen bench test apparatus

APPENDIX E

OPERATING DATA AND STATISTICAL PROCEDURES

OPERATING DATA - SCREENING/FLOTATION SYSTEM

Table E-1. OPERATIONAL DATA - 1969

Run no.	Date	Duration, min	Raw waste, gal.	Screen wash, gal.	Floated scum, gal.	Overflow rate, gpm/sq ft
691	6/4/69	123	378000	0	6200	2.63
692	6/4/69	70	189000	0	3450	2.31
693	6/7/69	103	302400	1600	3400	2.51
694	6/7/69	30	88200	800	900	2.51
695	6/22/69	75	201600	2000	1900	2.30
696	6/25/69	110	340200	<600	3500	2.64
697	6/26/69	150	441000	600	6250	2.51
698	6/27/69	105	277200	600	6700	2.20
699	6/29/69	50	151200	<600	850	2.58
6910	7/2/69	180	554400	<600	4400	2.63
6911	7/11/69	75	226800	800	2100	2.58
6912	7/16/69	35	100800	3200	400	2.46
6913	7/17/69	60	163300	1200	700	2.33
6914	7/23/69	75	226800	5200	1200	2.58
6915	7/26/69	40	100800	<600	450	2.15
6916	8/7/69	50	138600	4800	200	2.37
6917	8/9/69	150	395640	3600	1700	2.25
6918	8/11/69	65	190680	<600	460	2.51
6919	9/4/69	35	100800	1200	450	2.46
6920	9/5/69	90	277200	600	1850	2.63
6921	9/6/69	60	176400	<600	540	2.51
6922	9/23/69	65	201600	600	700	2.65
6923	9/29/69	180	453600	600	2200	2.15
6924	9/29/69	47	143640	<600	310	2.61
6925	10/10/69	65	176400	<600	3850	2.32
6926	10/10/69	243	705600	8400	1700	2.48
6927	10/12/69	75	226800	1200	750	2.58
6928	10/31/69	55	163800	2400	600	2.55
6929	11/2/69	45	113400	1800	250	1.76
6930	11/3/69	110	327600	1800	1150	2.55

Table E-1. (Continued)

OPERATIONAL DATA - 1969

Run no.	Rainfall		Operating pressure, psig	Pressurized flow rate, gpm	Chemical addition	
	Inches	In/hr			C-31 mg/l	Cl_2 mg/l
691	0.42	0.13	50	600	0	0
692	0.17	0.68	40	650	0	0
693	0.20	0.15	50	850	0	0
694	0.10	0.10	50	850	0	0
695	0.25	0.32	50	900	0	10
696	0.50	0.50	50	900	0	0
697	1.75	1.17	50	900	0	10
698	0.50	0.40	50	600	0	8
699	1.00	0.70	60	700	0	10
6910	1.50	2.30	60	700	0	10
6911	0.27	0.40	60	475	0	10
6912	0.12	1.50	55	600	0	10
6913	0.45	0.45	50	900	0	10
6914	0.17	0.35	60	400	0	0
6915	0.40	0.35	60	400	0	0
6916	0.10	0.40	60	450	5	0
6917	0.30	0.10	60	600	0	0
6918	0.45	1.60	60	450	3	0
6919	0.10	1.20	60	800	3	0
6920	0.05	2.10	60	650	3	0
6921	0.20	1.20	50	500	3	0
6922	0.14	0.30	50	500	3	0
6923			50	500	5	0
6924	0.70		50	500	0	0
6925	0.17	0.15	50	800	0	0
6926			60	400	3	0
6927	0.40	0.15	50	550	0	0
6928	0.12	0.10	50	550	2.5	0
6929	0.10		50	550	2.5	0
6930	0.50	0.30	50	550	5	0

Table E-1. (Continued)
OPERATIONAL DATA - 1970

Run no.	Date	Duration, min	Raw waste, gal.	Screen wash, gal.	Floated scum, gal.	Overflow rate, gpm/sq ft	
						High	Low
701	4/13/70	90.7	252000	1200	1050	4.75	3.56
703	4/9/70	47.6	126000	4800	500	4.52	3.39
704	5/11/70	49.7	119700	360	300	4.16	3.09
705	5/12/70	138.6	286020	60	500	3.53	2.65
706	5/15/70	52.3	117180	0	250	3.83	2.87
707	5/22/70	73.7	153720	1380	350	3.56	2.67
708	5/31/70	90.1	186480	3960	1000	3.54	2.65
709	6/1/70	90	178920	420	2050	3.40	2.55
7010	6/12/70	44.1	95760	120	1300	3.71	2.78
7011	6/26/70	75.1	142380	3300	1900	3.24	2.43
7012	6/26/70	68	143640	460	1700	3.61	2.71
7013	7/8/70	49.5	131040	2820	1000	4.52	3.39
7014	7/14/70	40	133560	1080	1000	5.71	4.28
7015	7/15/70	49.8	118440	480	500	4.06	3.05
7016	7/19/70	97.2	217980	60	1600	3.83	2.88
7017	7/27/70	66.6	147420	0	1050	3.79	2.84
7018	7/31/70	34.1	75600	240	150	3.79	2.84
7019	8/18/70	36.4	10200	1740	100	4.79	3.59
7020	9/2/70	51.8	152700	0	600	5.08	3.81
7021	9/3/70	95.6	229320	0	1150	4.10	3.08
7022	10/23/70	38	118440	2160	200	5.33	4.00
7023	10/26/70	64.5	153720	0	500	4.07	3.06
7024	10/27/70	149.1	322560	60	750	3.75	2.81
7025	10/31/70	95	241920	4260	600	4.35	3.27

Table E-1 (Continued)
OPERATIONAL DATA - 1970

Run no.	Rainfall		Operating pressure, psig	Pressurized flow rate, gpm	Chemical addition, mg/l		
	Inches	in/hr			C-31	$FeCl_3$	Cl_2
701	0.7	--	50	800	0	0	10
703	0.3	0.17	50	600	0	0	10
704	0.07	0.09	50	900	6	0	10
705	0.57	0.23	50	900	6	0	10
706	0.25	0.33	50	900	6	0	10
707	0.28	0.36	50	450	6	0	10
708	0.14	0.84	50	450	6	0	10
709	0.5	1.11	50	550	4.2	30	0
7010	0.33	0.11	50	550	4.6	29	0
7011	0.25	0.17	50	450	5.3	17	0
7012	0.10	0.09	60	350	3.9	16	0
7013	0.20	0.80	50	600	4.6	16	0
7014	0.22	0.18	55	950	3.5	21	0
7015	0.10	0.13	50	450	4.5	21	0
7016	0.25	0.13	50	450	4.5	21	0
7017	0.30	0.36	50	450	4.5	21	0
7018	0.45	2.25	50	450	4.5	21	0
7019	0.23	0.15	50	550	3.8	17.5	0
7020	0.25	0.24	50	550	3.8	17.5	0
7021	0.35	0.18	50	550	3.8	17.5	0
7022	0.15	0.10	50	600	0.5[a]	15	0
7023	0.70	0.35	50	600	0.5[a]	15	0
7024	0.40	0.10	50	600	0.5[a]	25	0
7025	0.32	--	50	600	4	25	0

[a] Herco Floc 810 used for these runs.

Table E-2. RAW WASTE CHARACTERISTICS - FIRST FLUSHES (1969-1970 Data)
(mg/l except pH)

Run no.	COD	BOD	Suspended solids	Volatile suspended solids	Total nitrogen	pH	Total solids	Total volatile solids	Ortho phosphate as PO_4	Coliform, per ml
691	676	172	642	391	21.3	7.20	815	431	3.92	62,000
695	615	180	538	310	18.0	7.08	798	480	2.47	110,000
6911	920	180	1180	678	--	6.80	1322	780	--	41,000
6912	472	--	496	253	--	7.2	779	300	4.24	65,000
6914	574	180	554	322	20.7	6.7	833	488	2.88	16,000
6916	531	89	405	310	18.6	6.9	677	443	2.24	150,000
6919	642	170	312	244	23.3	7.0	869	536	5.96	310,000
702	617	224	582	228	18.9	6.90	913	494	2.00	600,000
708	512	160	431	247	13.3	7.1	746	387	2.15	110,000
7011	390	212	232	156	8.8	7.1	732	433	0.68	16,650
7013	649	330	479	289	13.9	7.0	984	604	1.06	4,400
7022	372	145	415	273	19.5	7.35	--	--	2.46	220,000

Table E-3. RAW WASTE CHARACTERISTICS - EXTENDED OVERFLOWS - 1969 DATA
(mg/l except pH)

Run no.	COD	BOD	Suspended solids	Volatile suspended solids	Total nitrogen	pH	Total solids	Total volatile solids	Ortho phosphate	Coliform, per ml
691	108	38	112	58	4.1	7.10	244	121	1.18	9,500
692	220	43	365	145	8.1	6.80	502	215	1.76	39,000
693	241	--	169	117	---	7.60	560	302	---	---
694	173	--	158	80	---	7.60	312	168	---	---
695	207	65	168	102	6.4	7.10	302	176	0.88	36,000
696	87	17	88	46	2.3	6.80	188	102	0.60	5,700
697	66	7	192	55	2.0	7.20	157	90	0.30	1,300
698	47	7	57	29	1.4	7.45	170	86	0.37	7,800
699	59	--	148	43	---	7.00	208	70	---	6,200
6910	78	12	208	66	3.1	7.10	280	102	0.36	19,000
6911	188	49	276	105	---	6.40	384	162	---	20,000
6913	223	--	176	120	---	7.45	541	250	0.52	38,000
6915	118	--	116	62	---	7.30	197	118	0.24	1,300
6917	185	--	104	78	7.6	7.10	445	222	3.26	---
6918	137	37	192	82	4.8	7.00	278	170	0.50	1,500
6920	127	31	114	62	4.3	6.85	247	160	0.30	160,000
6921	114	25	102	64	4.6	6.80	226	108	0.78	55,000
6922	248	--	165	117	8.1	7.20	478	296	1.00	82,000
6923	163	61	104	68	8.4	7.18	279	152	1.20	1,400
6924	125	31	129	66	3.8	7.18	218	105	0.91	330
6925	118	39	70	22	8.8	7.60	478	225	1.24	55,000
6926	95	29	141	65	3.3	7.10	199	82	0.36	12,000
6927	94	36	56	45	---	7.20	269	128	0.72	78,000
6928	334	124	180	138	10.2	6.90	450	272	2.12	200,000
6929	195	70	87	63	9.1	7.30	457	244	1.88	180,000
6930	217	65	87	66	7.0	7.40	390	224	2.26	110,000

Table E-3 (Continued)
RAW WASTE CHARACTERISTICS - EXTENDED OVERFLOWS - 1970 DATA
(mg/l except pH)

Run no.	COD	BOD	Suspended solids	Volatile suspended solids	Total nitrogen	pH	Total solids	Total volatile solids	Ortho phosphate as PO_4	Coliform, per ml
701	143	36	151	75	2.9	7.45	295	112	0.83	--
703	206	91	218	88	7.4	7.1	412	200	1.34	270,000
704	141	58	109	39	5.4	7.4	676	267	1.08	12,000
705	199	35	316	193	6.3	6.8	511	203	1.1	--
706	140	28	149	75	3.7	7.7	466	246	0.5	700
707	211	101	228	146	7.5	6.9	533	298	1.17	340,000
709	168	37	148	86	4.4	7.35	343	160	0.92	73,000
7012	177	67	119	81	6.3	7.2	577	291	0.96	12,000
7014	191	--	232	139	5.55	7.2	441	220	0.06	35,500
7015	162	--	140	85	4.9	6.9	415	177	0.47	118,800
7016	130	--	135	95	--	7.1	304	145	0.71	7,660
7018	244	--	337	183	--	7.1	566	246	---	--
7019	286	113	264	164	6.95	7.4	574	250	2.28	3,800
7020	153	53	466	204	3.4	7.15	673	304	0.74	160,000
7021	90	25	118	63	2.4	7.05	266	116	0.77	4,800
7023	169	67	107	73	8.7	7.7	---	---	2.73	55,000
7024	178	54	171	125	4.9	7.1	---	---	0.74	26,000
7025	139	66	123	103	6.4	7.4	---	---	1.78	117,000

Table E-4. SCREENED WATER QUALITY - FIRST FLUSHES (1969-1970 DATA)
(mg/l except pH)

Run no.	COD	BOD	Suspended solids	Volatile suspended solids	pH	Total solids	Total Volatile solids
695	168	51	170	91	7.75	833	372
6912	449	--	424	234	7.0	725	300
6914	281	120	260	150	7.0	536	302
6916	432	71	290	290	6.9	290	369
6919	510	169	286	236	6.8	848	520
702	321	133	306	126	7.30	716	303
708	306	93	272	128	7.3	623	293
7011	254	141	180	106	6.8	665	394
7013	611	295	418	231	6.8	906	552
7022	262	113	331	173	7.4	---	---

Table E-5. SCREENED WATER QUALITY - EXTENDED OVERFLOW - 1969 DATA
(mg/l except pH)

Run no.	COD	BOD	Suspended solids	Volatile suspended solids	pH	Total solids	Total volatile solids
693	132	--	123	69	7.70	463	234
694	165	--	124	64	7.40	290	156
695	159	50	148	77	6.92	301	165
696	49	15	68	36	7.00	184	94
697	26	7	152	42	7.20	226	84
698	51	5	40	24	7.40	142	79
699	49	--	132	32	6.90	196	77
6910	60	9	156	50	7.25	258	100
6911	144	37	249	107	6.80	330	173
6913	163	--	111	38	6.90	231	100
6915	89	--	67	39	7.10	133	70
6917	141	--	62	47	7.12	404	224
6918	103	31	139	55	7.05	244	147
6920	76	21	45	32	6.93	205	150
6921	91	--	88	51	6.90	231	105
6922	184	--	99	74	7.25	396	242
6923	138	54	95	60	7.22	273	125
6924	105	27	124	57	7.10	189	85
6925	122	41	79	26	7.62	422	194
6926	73	20	96	45	7.10	169	76
6927	78	28	47	35	7.30	289	129
6928	260	90	105	55	6.90	412	236
6929	171	59	72	54	7.40	411	226
6930	200	60	71	44	7.30	369	202

Table E-5. (Continued)
SCREENED WATER QUALITY - EXTENDED OVERFLOW - 1970 DATA
(mg/l except pH)

Run no.	COD	BOD	Suspended solids	Volatile suspended solids	pH	Total solids	Total volatile solids
701	133	35	138	66	7.5	294	106
703	183	75	180	95	7.2	372	193
704	126	15	52	16	7.6	635	270
705	121	26	198	122	7.2	469	174
706	90	18	86	44	7.6	410	213
707	156	51	126	61	7.2	487	207
709	84	18	55	39	6.6	344	183
7012	123	49	104	53	7.1	404	189
7014	183	--	226	114	6.8	441	213
7015	137	--	132	63	6.7	439	205
7016	80	--	98	56	6.6	281	141
7018	169	--	272	125	6.8	510	214
7019	201	71	202	108	7.4	543	303
7020	122	35	252	86	7.1	528	192
7021	57	13	131	156	6.9	298	148
7023	136	58	99	73	7.6	---	---
7024	82	29	85	64	---	---	---
7025	132	47	161	101	6.6	---	---

Table E-6. EFFLUENT WATER QUALITY - FIRST FLUSHES (1969-1970)
(mg/l except pH & coliform)

Run no.[a]	COD	BOD	Suspended solids	Volatile suspended solids	Total nitrogen	pH	Total solids	Total volatile solids	Ortho phosphate as PO_4	Coliform per ml
691	177	74	166	92	15.4	7.50	714	320	8.10	26,000
6911	137	39	130	62	---	7.00	411	221	---	40
6912	245	--	224	102	---	8.00	902	437	2.51	---
6914	179	64	109	57	9.0	7.10	533	289	1.84	16,000
6916	173	51	89	64	9.0	7.12	627	314	1.10	80,000
6919	263	94	108	96	13.5	7.53	959	460	3.02	8
702	64	24	102	61	2.7	7.7	1251	481	0.46	1
702[b]	63	21	84	51	2.4	7.6	1183	410	0.22	1
708	168	66	105	57	7.4	7.2	440	206	1.47	180
708[b]	197	103	145	73	8.2	7.2	519	248	2.79	1500
7011	143	85	70	38	4.0	6.8	545	297	0.08	5700
7011[b]	157	76	60	33	4.0	6.8	412	253	0.03	5700
7013	285	149	135	58	7.5	7.0	690	406	0.07	3150
7013[b]	337	178	165	90	8.1	7.1	676	389	0.06	500
7022	73	18	65	47	5.4	7.6	---	---	1.32	---
7022[b]	68	22	59	48	4.6	7.6	---	---	1.01	1400

a. Overflow rate ~2.5 gpm/sq ft except where noted.
b. Overflow rate ~3.75 gpm/sq ft.

Table E-7. EFFLUENT WATER QUALITY - EXTENDED OVERFLOW - 1969 DATA
(mg/l except pH and coliform)

Run no.	COD	BOD	Suspended solids	Volatile suspended solids	Total nitrogen	pH	Total solids	Total volatile solids	Ortho phosphate	Coliform, per ml
691	107	36	120	58	5.8	7.25	320	147	2.15	9,000
692	122	25	218	76	6.2	6.60	380	172	1.76	61,000
693	60	--	59	14	---	8.15	725	306	---	----
695	105	52	95	43	4.2	7.60	606	296	1.13	<1
696	50	13	58	24	2.2	7.10	258	140	0.90	<0.04
697	25	7	138	38	1.3	7.20	234	84	0.40	<0.04
698	30	11	63	30	1.2	7.45	174	95	0.40	<0.04
699	34	--	89	11	---	7.10	194	77	---	0.02
6910	51	6	142	40	1.8	7.25	300	125	0.44	<0.02
6911	102	25	194	59		7.10	286	206		0.1
6913	134		65	44		7.70	412	220	1.77	<50
6915	69		55	34		7.90	434	203	0.80	10,000
6917	122		38	31	10.5	7.20	429	240	2.82	----
6918	67	22	34	15	4.5	7.10	475	185	3.86	1,000
6920	57	15	34	27	4.3	6.98	134	73	0.58	400
6921	63	6	44	32	4.3	7.00	222	98	0.67	15
6922	131		56	46	5.6	7.50	544	282	1.26	150
6923	99	43	49	37	7.2	7.32	250	109	0.81	8
6924	72	24	67	31	4.0	7.20	156	56	0.83	30
6925	54	24	38	10	6.2	7.85	457	214	1.22	19,000
6926	30	8	35	17	2.3	7.00	115	46	0.42	8,200
6927	45	17	22	17	---	7.10	221	100	0.61	55,000
6928	189	73	91	53	6.8	7.00	335	184	1.58	120,000
6929	149	48	48	34	6.9	7.30	358	176	1.42	69,000
6930	207	54	54	38	6.9	7.30	342	182	1.96	110,000

Table E-7. (Continued)
EFFLUENT WATER QUALITY - EXTENDED OVERFLOW - 1970 DATA HIGH
OVERFLOW RATES
(mg/l except pH and coliform)

Run No.	COD	BOD	Suspended solids	Volatile suspended solids	Total nitrogen	pH	Total solids	Total volatile solids	Ortho phosphate	Coliform per ml
701	86	24	110	49	2.9	7.7	519	168	.58	5,000
703	203	74	161	89	6.4	7.6	541	236	1.9	<1
704	102	26	73	37	5.4	7.6	702	290	1.5	<1
705	51	11	65	38	4.5	7.6	341	127	1.4	3
706	39	13	50	27	3.0	7.6	390	194	0.6	.06
707	121	42	114	56	5.7	7.3	385	189	1.38	33
709	66	18	35	23	3.4	6.8	279	139	0.09	>10,000
7012	113	46	76	36	4.8	6.8	465	234	0.01	11,200
7014	135	--	78	45	5.4	6.9	421	199	0.03	8,200
7015	99	--	84	44	3.6	6.6	349	168	0.03	49,500
7016	38	--	23	17	---	6.6	184	91	0	1,960
7018	67	--	47	39	---	6.8	295	137	---	---
7019	71	23	67	35	2.5	8.0	751	305	0.28	600
7020	56	29	172	63	2.0	7.4	683	297	0.06	73,000
7021	30	5	39	20	1.8	7.0	184	108	0.12	1,700
7023	92	36	70	47	6.1	7.6	---	---	0.31	49,000
7024	87	29	75	38	3.6	7.3	---	---	0.43	15,300
7025	57	24	39	31	4.0	6.6	---	---	0.06	6,000

Table E-7. (Continued)

EFFLUENT WATER QUALITY - EXTENDED OVERFLOW 1970 DATA - LOW OVERFLOW RATES

(mg/1 except pH and coliform)

Run No.	COD	BOD	Suspended Solids	Volatile Suspended Solids	Total Nitrogen	pH	Total Solids	Total Volatile Solids	Ortho Phosphate	Coliform per ml
701	98	23	94	40	2.9	7.8	535	174	.37	5,800
703	184	72	141	79	2.7	7.6	508	229	2.0	<1
704	92	18	25	4	5.3	7.7	616	241	1.1	<1
705	55	11	65	40	4.5	7.6	311	123	---	9
706	33	7	29	20	2.9	7.6	445	237	0.4	.02
707	102	39	73	41	5.2	7.3	343	170	1.29	38
709	57	18	26	21	3.4	6.8	274	152	0.06	>10,000
7012	104	43	57	34	4.4	6.8	499	243	0.05	14,200
7014	122	---	74	44	3.9	7.0	373	183	0.03	6,330
7015	92	---	88	41	2.6	6.7	350	163	0.03	28,000
7016	34	---	20	15	---	6.7	200	91	0	1,400
7018	61	---	46	30	---	6.8	285	116	---	---
7019	102	34	76	37	3.1	7.7	621	274	0.95	2,100
7020	49	12	71	29	1.9	7.2	567	248	0.18	32,000
7021	38	6	33	19	1.8	7.0	198	116	0.09	1,400
7023	107	33	55	37	5.3	7.4	---	---	0.15	38,000
7024	69	26	59	49	3.8	7.1	---	---	0.43	14,400
7025	69	25	51	40	3.9	6.6	---	---	0.06	28,000

Table E-8. DISSOLVED COD AND TOC DATA (1970)
(mg/1)

Run No.	Raw Waste			Screened Effluent			System Effluent		
	Dissolved COD	Total TOC	Dissolved TOC	Dissolved COD	Total TOC	Dissolved TOC	Dissolved TOC	Total TOC	Dissolved TOC
701	32	35	12	33	31	12	27	24	8
702	147	237	57	107	121	41	64	23	18
703	103	75	39	97	53	37	122	74	48
704	52	42	18	63	38	20	59	31	20
705	47	71	16	54	36	15	48	16	15
706	49	41	17	44	29	14	34	18	12
707	73	--	--	84	--	--	66	--	--
708	102	--	--	117	--	--	105	--	--
709	54	--	--	38	--	--	43	--	--
7011	154	--	--	147	--	--	113	--	--
7012	68	--	--	71	--	--	80	--	--
7013	313	249	128	336	235	137	219	117	86
7014	101	--	--	89	--	--	70	--	--
7015	55	--	--	52	--	--	39	--	--
7016	28	--	--	26	--	--	27	--	--
7018	36	79	--	28	61	--	33	21	--
7019	92	139	36	94	91	31	62	44	24
7020	47	38	13	36	27	12	49	7	9
7021	45	--	17	46	--	17	34	--	13
7022	60	--	--	59	--	--	34	--	--
7023	71	--	--	56	--	--	56	--	--
7024	37	--	--	34	--	--	38	--	--
7025	55	57	25	45	49	18	43	27	14

Table E-9. SCREEN BACK WASH & FLOATED SCUM QUALITY 1969 DATA

(mg/1 except pH)

	Screen Back Wash Quality			
Run #	pH	Total Solids	Total Volatile Solids	Suspended Solids[a]
693	--	--	--	--
694	--	--	--	--
695	6.8	1688	1388	1554
696	6.8	643	538	543
697	--	--	--	--
698	7.8	296	220	183
699	--	--	--	--
6910	7.1	1443	1025	1371
6911	6.5	2542	1814	2434
6912	7.0	2192	1450	1909
6913	7.2	1865	1100	1500
6914	7.0	--	--	--
6915	--	--	--	--
6916	6.9	3638	2486	3366
6917	6.6	1776	1406	1435
6918	--	--	--	--
6919	6.8	2303	1830	1746
6920	7.1	2431	1813	2298
6921	--	--	--	--
6922	7.1	4185	2533	3872
6923	7.2	890	694	715
6924	--	--	--	--
6925	--	--	--	--
6926	7.4	2901	972	2843
6927	--	--	--	--
6928	6.8	1600	1236	1330
6929	7.2	1623	1244	1253
6930	7.3	1322	1048	1019

---

a. Calculated based on dissolved solids in raw waste

Table E-9. (Continued)
SCREEN BACK WASH & FLOATED SCUM QUALITY 1969 DATA
(mg/l except pH)

	Floated Scum Quality			
Run #	pH	Total Solids	Total Volatile Solids	Suspended Solids[a]
693	6.8	2395	1520	2004
694	--	--	--	--
695	7.2	4005	2390	3879
696	7.1	584	330	484
697	7.2	686	332	613
698	7.5	385	202	272
699	--	--	--	--
6910	7.3	1439	647	1367
6911	6.6	36860	19958	36720
6912	7.0	14282	7550	13999
6913	7.0	19081	10700	18716
6914	--	11131	6919	10852
6915	7.0	3705	2244	3624
6916	6.6	22627	13403	22355
6917	6.8	4687	3163	4346
6918	7.0	7694	3544	7608
6919	6.8	13650	8450	13093
6920	7.0	12168	6644	12035
6921	6.9	3111	1408	3087
6922	7.0	2291	1848	1978
6923	6.9	13228	8082	13053
6924	7.1	6699	3471	6610
6925	7.5	2508	1097	2100
6926	7.3	11361	5002	11303
6927	7.0	1705	1132	1492
6928	6.8	3268	2100	2938
6929	6.8	7027	5045	6657
6930	7.0	2804	2020	2501

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a. Calculated based on dissolved solids in raw waste.

Table E-10. SCREEN BACKWASH AND FLOATED SCUM QUALITY - 1970 DATA
(mg/l except pH)

	Screen Backwash				Floated Scum			
Run No.	Screen pH	Total Solids	Total Volatile Solids	Suspended solids[a]	pH	Total Solids	Total Volatile Solids	Suspended solids[a]
701	7.7	1655	913	1435	7.5	2547	1455	2403
702	7.2	3929	3017	3599	7.3	8044	4549	7713
703	6.9	1891	1310	1697	7.2	4431	2284	4237
704	---	---	---	---	7.4	7374	4408	6807
705	---	---	---	---	7.2	34981	9835	34663
706	---	---	---	---	7.5	8399	4484	8082
707	7.1	3522	2723	3142	6.9	11379	5157	11074
708	---	---	---	---	7.2	21201	9074	20866
709	6.6	3976	3073	3781	6.6	27416	10406	27221
7011	6.7	3459	2387	2959	6.6	11601	5618	11101
7012	---	---	---	---	6.8	15675	7476	15217
7013	6.9	2817	2068	2312	6.8	13427	6829	12922
7014	---	---	---	---	6.9	6014	2606	5805
7015	---	---	---	---	6.6	15452	7005	15177
7016	6.7	1191	893	1022	6.6	13812	5747	13643
7018	7.1	2945	1987	2716	7.0	17062	6249	16836
7019	7.1	2307	1636	1940	7.5	3138	1589	2771
7020	---	---	---	---	---	---	---	---
7021	---	---	---	---	---	16300	4360	16152
7022	---	---	---	---	7.2	24064	9781	---
7023	---	---	---	---	7.4	12709	6024	---
7024	---	---	---	---	7.1	3782	1807	---
7025	6.7	---	---	---	6.6	24026	11683	---

a. Calculated based on dissolved solids in raw waste.

Table E-11. FIRST FLUSH EVALUATIONS (RAW COMBINED SEWER OVERLFOW QUALITY) (1969-1970)

Days Since Last Overflow	Run No.	COD	BOD mg/1	Suspended Solids mg/1	Volatile Suspended Solids mg/1
0	703	206	91	218	88
0	692	220	43	365	145
0	694	173	--	158	80
0	6924	125	31	129	66
0	6930	217	65	87	66
0	705	199	35	316	193
0	709	168	37	148	86
0	7012	117	49	119	81
1	697	66	7	---	26
1	698	47	7	57	29
1	6913	223	---	176	120
1	6920	127	31	114	62
1	6921	114	25	102	64
1	6926	95	29	141	65
1	6927	94	36	56	45
1	7015	191	---	140	85
1	7021	90	25	118	63
1	7024	178	54	171	125
2	699	59	---	148	43
2	6911	185	---	104	78
2	706	140	28	149	75
2	704	141	58	109	39
2	706	140	28	149	75
2	7023	169	67	107	73
3	693	241	---	169	117
3	696	87	17	88	46

Table E-11. (Continued)
FIRST FLUSH EVALUATIONS (RAW COMBINED SEWER OVERFLOW QUALITY)
(1969-1970)

Days Since Last Overflow	Run No.	COD	BOD mg/1	Suspended Solids mg/1	Volatile Suspended Solids mg/1
3	6915	118	---	116	62
3	6925	195	70	87	63
3	7016	130	---	135	95
3	7018	244	---	337	183
3	7025	139	66	123	103
4	6910	78	12	208	66
5	6912	472	---	496	253
5	7014	191	101	232	139
6	6914	574	18	554	322
6	6923	163	61	104	68
6	707	211	101	228	146
8	6911	920	180	1180	678
8	708	512	160	431	247
11	6918	137	37	192	82
11	6925	118	39	70	22
11	7013	649	330	479	289
12	6916	531	89	405	310
13	7011	390	212	232	156
14	7020	153	53	466	204
15	695	615	180	538	310
17	6922	248	---	165	117
17	7019	286	113	264	164
18	691	676	172	642	391
19	6928	334	124	180	138
19	7022	372	145	415	273
24	6919	642	170	312	244
26	702	617	224	582	228

Table E-12. FIRST FLUSH REMOVALS IN PERCENT (1969-1970)

	Screen				Overall System				
Run No. A	COD	BOD	SS	VSS	COD	BOD	SS	VSS	N
691	--	--	--	--	73.8	57.0	74.1	76.5	27.7
695	72.7	71.7	68.4	70.6	--	--	--	--	--
6911	--	--	--	--	85.1	78.3	89.0	90.9	--
6912	4.9	--	14.5	7.5	48.1	--	54.8	59.7	--
6914	51.1	33.3	53.1	53.4	68.8	64.4	80.3	82.3	56.5
6916	18.6	20.2	28.4	17.1	67.4	42.7	78.0	79.4	51.6
6919	20.6	0.6	8.3	3.3	59.0	44.7	65.4	60.7	42.1
702[b]	--	--	--	--	89.7	90.6	85.6	77.6	87.3
702	48.0	40.6	47.4	44.7	89.6	89.2	82.5	73.3	85.7
708	40.2	41.9	36.9	48.2	67.2	58.8	75.6	76.9	44.4
708[b]	--	--	--	--	61.5	35.6	66.4	70.5	38.3
711	34.9	33.5	22.4	32.1	63.3	59.9	69.8	75.6	55.0
711[b]	--	--	--	--	59.7	64.2	74.1	78.9	55.0
713	5.9	10.6	12.7	20.1	56.1	54.9	71.8	79.9	46.0
713[b]	--	--	--	--	48.1	46.1	65.6	68.9	41.7
722	29.6	22.1	20.2	29.3	80.4	87.6	84.3	82.8	72.3
722[b]	--	--	--	--	81.7	84.8	85.8	82.4	76.4

a. Overflow rate ~2.5 gpm/sq ft except where noted.
b. Overflow rate ~3.75 gpm/sq ft.

Table E-13. EXTENDED OVERFLOW REMOVALS (%) - 1969 DATA

	Screen				Overall System				
Run #	COD	BOD	SS	VSS	COD	BOD	SS	VSS	N
69-2	---	---	---	---	44.5	41.9	40.3	47.6	23.5
69-3	45.2	---	27.2	41.0	75.1	---	65.1	88.0	---
69-4	4.6	---	21.5	20.0	---	---	---	---	---
69-5	23.2	23.1	11.9	24.5	49.3	20.0	43.5	57.8	34.4
69-6	43.7	11.7	22.7	21.7	42.5	23.5	34.1	47.8	4.3
69-7	60.6	0	20.8	23.6	62.1	0	28.1	30.9	35.0
69-8	---	28.6	29.8	17.2	36.2	---	10.5	3.4	14.3
69-9	16.9	---	10.8	25.6	42.4	---	39.9	74.4	---
69-10	23.1	25.0	25.0	24.2	34.6	50.0	31.7	39.4	41.9
69-11	23.4	24.5	9.8	43.8	45.7	49.0	29.7	43.8	---
69-13	26.9	---	36.9	68.3	39.9	---	63.1	63.3	---
69-15	24.6	---	42.2	37.1	41.5	---	52.6	45.2	---
69-17	23.8	---	40.4	39.7	34.1	---	63.5	60.3	---
69-18	24.8	16.2	27.6	32.9	51.1	40.5	82.3	81.7	6.2
69-20	40.2	32.3	60.5	48.4	48.8	51.6	70.2	56.5	
69-21	20.2	---	13.7	20.3	44.7	76.0	56.9	50.0	6.8
69-22	25.8	---	40.0	36.8	47.2	---	66.1	60.7	30.9
69-23	15.3	11.5	8.6	11.7	39.3	29.5	52.9	45.6	14.3
69-24	16.0	12.9	3.8	13.6	42.4	22.6	48.1	53.0	---
69-25	3.4	5.1	12.9	18.2	54.2	38.5	45.7	54.5	29.5
69-26	23.2	31.0	31.9	30.7	68.4	72.4	75.2	73.8	30.3
69-27	17.0	22.2	16.1	22.2	52.1	52.8	60.7	62.2	---
69-28	22.2	27.4	41.7	60.1	43.4	41.1	49.4	61.6	33.3
69-29	12.3	15.7	17.2	14.3	23.6	31.4	44.8	46.0	24.2
69-30	7.8	7.7	18.4	33.3	4.6	16.9	37.9	42.4	1.4

Table E-13. (Continued)

EXTENDED OVERFLOW REMOVALS (%) 1970 DATA - HIGH OVERFLOW RATES

Run	Overall System				
No.	COD	BOD	SS	VSS	N
701	39.9	33.3	27.2	34.7	0
703	1.5	18.7	26.7	1.1	13.5
704	27.7	55.2	33.0	51.2	0
705	74.4	68.6	79.4	80.3	27.7
706	72.1	53.6	66.4	64.0	23.0
707	42.7	58.4	50.0	61.6	24.0
709	60.7	51.4	76.4	73.3	22.7
7012	36.2	31.4	36.1	55.6	23.8
7014	29.3	---	66.4	67.6	3.6
7015	38.9	---	40.0	48.2	26.5
7016	70.8	---	83.0	82.1	---
7018	72.5	---	86.1	78.7	---
7019	75.2	79.7	74.6	78.7	64.0
7020	63.4	45.3	63.1	69.1	41.2
7021	66.7	80.0	67.0	68.3	25.0
7023	45.6	46.3	34.6	35.6	29.9
7024	51.1	46.3	56.1	69.6	26.5
7025	60.0	63.6	68.3	69.9	37.5

Table E-13. (Continued)

EXTENDED OVERFLOW REMOVALS (%) 1970 DATA - LOW OVERFLOW RATES

Run	Screen				Overall System				
No.	COD	BOD	SS	VSS	COD	BOD	SS	VSS	N
701	7.0	2.8	8.6	12.0	31.5	36.1	37.7	46.7	0
703	11.2	17.6	17.4	---	10.7	20.9	35.3	10.2	63.5
704	10.6	74.1	52.3	59.0	34.8	69.0	77.1	89.7	0
705	39.2	25.7	37.3	36.8	72.4	68.6	79.4	79.3	27.8
706	35.7	35.7	42.3	41.3	74.6	75.0	80.5	73.3	18.8
707	26.1	49.5	44.7	58.2	51.7	61.4	68.0	71.9	30.7
709	50.0	51.4	62.8	54.7	66.1	51.4	82.4	75.6	22.7
7012	30.5	26.9	12.6	34.6	41.2	35.8	52.1	58.0	30.2
7014	4.2	10.6	2.6	18.0	36.1	---	68.1	68.4	29.5
7015	15.4	---	5.7	25.9	43.2	---	37.1	51.8	46.9
7016	38.0	---	27.0	32.0	73.8	---	85.2	84.2	---
7018	31.0	---	19.0	32.0	75.1	---	86.4	83.6	---
7019	30.0	37.0	23.0	34.0	64.3	69.9	71.2	77.4	55.4
7020	20.0	34.0	46.0	58.0	68.0	77.4	84.8	85.8	44.1
7021	37.0	48.0	---	11.0	57.8	76.0	72.0	69.8	25.0
7023	19.5	13.4	7.5	---	36.7	50.7	48.6	49.3	39.2
7024	53.9	46.3	50.3	48.8	62.1	51.9	65.5	60.8	23.5
7025	5.0	28.8	---	2.0	50.4	62.1	58.5	61.2	39.1

Table E-14. SUSPENDED SOLIDS MASS BALANCE - 1969 DATA

Run No.	Pounds SS In	Pounds SS Out	Pounds SS Left in Tank	Pounds SS Screen Wash	Pounds SS Scum	Balance % (A)
691	353	372	80	0	---	-28
692	575	337	145	0	---	+16
693	426	146	39	---	58	+57
695	282	157	63	26	63	- 9
696	250	163	39	---	14	+14
697	706	499	92	---	31	+12
698	132	141	42	---	15	-50
699	187	111	59	---	---	+ 9
6910	961	650	94	---	50	+17
6911	522	362	86	16	84	- 5
6912	417	181	48	51	47	+22
6913	240	88	43	15	109	- 6
6915	97	46	37	---	15	- 1
6917	343	124	25	43	62	+26
6920	263	79	23	12	191	-16
6921	150	64	29	---	13	+29
6922	277	94	37	19	12	+41
6923	393	184	33	4	239	-17
6924	154	80	45	---	17	+ 8
6925	103	54	25	---	68	-43
6926	829	203	23	199	160	+29
6927	106	41	15	---	11	+37
6928	246	122	60	13	15	+14
6929	82	45	32	19	17	-37
6930	238	146	36	15	25	+ 7

a. (+) Excess solids in; (-) Excess solids out.

Table E-14. (Continued)
SUSPENDED SOLIDS MASS BALANCE - 1970 DATA

Run No.	Pounds SS In	Pounds SS Out	Pounds SS Left In Tank	Pounds SS Screen Wash	Pounds SS Scum	Balance % (A)
701	316	211	68	14	21	+ 1
703	228	151	100	67	18	-47
704	108	48	33	--	17	+ 9
705	750	154	43	--	144	+55
706	145	38	26	--	17	+44
707	291	120	63	36	32	+14
708	667	181	80	--	173	+35
709	220	44	20	38	463	-157
7011	274	74	43	81	175	-36
7012	142	76	43	--	215	-135
7013	481	158	100	54	107	+13
7014	257	83	50	--	48	+30
7015	138	84	57	--	63	-48
7016	244	40	15	5	181	+ 1
7018	211	29	31	54	21	+36
7019	224	60	48	28	2	+35
7021	225	68	24	--	154	- 9
7022	408	60	41	--	40	+65
7023	137	80	42	--	53	-28
7024	458	179	44	--	24	+46
7025	247	89	30	--	120	+ 3

a. (+) Excess solids in; (-) Excess solids out.

Table E-15. SCREENING/FLOTATION PILOT UNIT OPERATIONAL DATA, 1971-1972

Run No.	Date	Duration, min.	Raw waste, gal.	Screen wash, gal.	Floated scum, gal.	Overflow rate, gpm/sq ft		Operating pressure, psig	Pressurized flow rate gpm	Chemical addition,		
						High	Low			$FeCl_3$ mg/l	Poly mg/l	Cl mg/l
71-2	8/14/71	75.6	161,280	0	1150	2.7	5.5	50	500	25	-	10
71-3	8/22/71	56.4	128,520	360	350	2.9	5.9	50	525	25	-	10
71-4	8/24/71	71.3	156,240	2040	250	2.8	5.6	50	525	25	-	10
71-5	9/19/71	51.6	123,480	1800	400	3.1	6.2	50	500	21	5	--
71-6	10/3/71	122.4	284,500	1620	400	3.0	6.0	50	500	25	5	10
72-1	7/12/72	52.5	118,755	0	250	5.8	2.9	50	400	25	5	--
72-2	7/17/72	54.0	108,360	780	350	5.2	2.6	50	500	25	5	--
72-3	7/26/72	72.0	158,760	2820	400	5.7	2.8	45	500	25	5	--

Table E-16. RAW WASTE CHARACTERISTICS EXTENDED OVERFLOWS, 1971-1972 DATA
(mg/l except pH)

Run No.	BOD	Suspended solids	Volatile suspended solids	Kjeldahl nitrogen	pH	Total solids	Total volatile solids	Ortho phosphate	Coliform per ml	TOC	TIC
71-2	8	107	31	0.38	7.30	209	83	0.13	4,400	11	7
71-3	19	440	91	3.20	7.29	498	175	0.08	257,000	39	15
71-4	25	261	75	4.53	7.35	422	167	0.23	2,060,000	53	12
71-5	--	350	127	--	7.50	--	--	--	--	73	30
71-6	24	349	126	2.86	7.56	495	249	0.23	5,700	36	13
72-1	21	68	33	--	7.10	184	--	--	--	24	--
72-2	69	160	91	--	6.90	291	--	--	--	59	--
72-3	49	181	57	4.0	7.35	335	--	--	--	49	11
72-4	54	157	42	--	7.50	341	114	--	--	60	--

Table E-17. SCREENED WATER QUALITY EXTENDED OVERFLOW, 1971-1972 DATA
(mg/1 except pH)

Run No.	COD	BOD	Suspended solids	Volatile Suspended solids	pH	Total solids	total volatile solids	TOC	TIC
71-2	22	4	101	19	6.20	298	164	12	4
71-3	86	14	389	104	6.30	606	239	34	6
71-4	148	20	255	116	7.10	570	248	49	8
71-5	--	--	--	--	7.55	--	--	73	28
71-6	78	14	341	125	6.74	497	258	37	9
72-1	--	17	105	45	6.70	--	--	27	--
72-2	--	52	127	66	6.45	--	--	44	--
72-3	--	41	111	23	6.98	--	--	36	11
72-4	--	--	--	--	--	--	--	--	--

Table E-18. EFFLUENT WATER QUALITY - EXTENDED OVERFLOW 1971-1972 DATA - LOW OVERFLOW RATES
(mg/l except pH and coliform)

Run No.	BOD	Suspended solids	Volatile suspended solids	Kjeldahl nitrogen	pH	Total solids	Total volatile solids	Ortho phosphate	Coliform per ml	TOC	TIC
71-2	2	53	20	0.45	7.4	589	230	<.01	7	5	29
71-3	5	118	43	1.33	7.3	661	233	<.01	<.1	15	29
71-4	18	139	53	--	7.3	340	141	<.01	<.1	35	8
71-5	--	153	73	--	7.4	--	--	<--	--	36	32
71-6	11	88	58	167.00	7.1	354	161	<.01	4	16	2
72-1	9	53	29	--	7.6	381	--	--	--	15	--
72-2	27	69	32	--	6.7	291	--	--	--	25	--
72-3	17	26	3	--	7.0	189	--	--	--	17	10

Table E-19. EFFLUENT WATER QUALITY - EXTENDED OVERFLOW 1971-1972 DATA - HIGH OVERFLOW RATES (mg/l except pH.)

Run No.	BOD	Suspended Solids	Volatile suspended solids	Kjeldahl Nitrogen	pH	Total solids	Total volatile solids	Ortho phosphate	TOC	TIC
71-2	4	49	17	0.60	7.45	535	132	<.01	6	24
71-3	6	139	39	1.50	7.25	612	224	<.01	15	26
71-4	16	122	60	3.13	7.30	327	155	<.01	33	7
71-5	--	120	68	--	7.50	--	--	--	38	30
71-6	11	92	62	1.80	7.00	342	185	<.01	16	8
72-1	--	280	80	--	7.50	--	--	--	33	--
72-2	--	253	69	--	7.10	--	--	--	26	--
72-3	--	180	13	--	--	401	--	--	28	--

Table E-20. FLOATED SCUM QUALITY - 1971 DATA
(mg/l except pH and coliform)

		Floated Scum Qaulity		
Run #	pH	Total solids	Total volatile solids	Suspended solids[a]
71-2	--	26152	4733	26050
71-3	7.35	28009	4731	27951
71-4	7.55	--	--	--
71-5	7.45	--	--	--
71-6	7.12	29290	6608	29144

a. Calculated based on dissolved solids in raw waste.

Table E-21. EXTENDED OVERFLOW REMOVALS IN PERCENT 1971- DATA - HIGH OVERFLOW RATES

Overall System

Run No	TOC	BOD	SS	VSS	Kjeldahl nitrogen	Total phosphate
71-2	45.5	50.0	54.2	45.2	--	<92.3
71-3	61.5	68.4	68.4	57.1	53.1	<87.5
71-4	37.7	36.0	53.3	20.0	30.9	<95.7
71-5	47.9	--	65.7	46.5	--	--
71-6	55.6	54.2	73.6	50.8	37.1	<95.7

Table E-22. EXTENDED OVERFLOW REMOVALS IN PERCENT 1971-1972 DATA - LOW OVERFLOW RATES

Run	Screen				Overall System					
No.	TOC	BOD	SS	VSS	TOC	BOD	SS	VSS	Kjeldahl nitrogen	Total phosphate
71-2	--	50.0	5,6	38.7	54.5	75.0	50.5	35.5	--	<92.3
71-3	12.8	26.3	11.6	--	61.5	73.7	73.2	52.7	57.8	<87.5
71-4	7.5	20.0	2.3	--	34.0	28.0	46.7	29.3	--	<95.7
71-5	--	--	--	--	50.7	--	56.3	42.5	--	--
71-6	--	41.7	2.3	0.8	55.6	54.2	74.8	54.0	41.6	<95.7
72-1	--	19.0	--	--	37.5	57.1	22.1	12.1	30.8	52.7
72-2	25.4	24.6	20.6	27.5	57.6	60.9	56.9	64.8	4.0	61.2
72-3	26.5	16.3	38.7	59.6	65.3	65.3	85.6	94.7	60.0	75.0

Table E-23. SCREENING/FLOTATION PILOT UNIT OPERATIONAL DATA - 1973

Run No.	Date	Duration min.	Raw Waste, gal.	Screen wash, gal.	Floated scum, gal.	Overflow rate gpm/sq ft		Operating pressure, psig	Pressurized flow rate gpm	Chemical addition,	
						High	Low			$FeCl_3$, mg/l	Nalco 607, mg/l
73-1	7/19/73	69.2	116,718	0	300	5.35	2.68	50	400	25.0	4.0
73-2	7/26/73	51.6	87,948	900	400	5.39	2.70	50	400	25.0	4.7
73-3	8/8/73	59.1	115,788	420	350	6.69	3.34	50	650	26.4	4.2
73-4	8/9/73	33.5	79,438	0	200	7.75	3.87	45	650	13.5	2.2
73-5	9/4/73	44.7	106,587	2940	300	7.78	3.89	40	650	25.0	4.0
73-7	9/24/73	43.6	112,833	2040	400	4.09	2.73	40	600	26.4	4.0
73-8	9/28/73	122.1	308,763	1200	750	4.01	2.68	40	600	23.7	3.9
73-9	10/1/73	32.2	79,202	480	200	3.99	2.66	40	650	30.9	5.4
73-10	10/4/73	56.25	166,163	300	600	4.62	3.08	40	650	26.2	6.7

Table E-24. RAW WASTE CHARACTERISTICS EXTENDED OVERFLOWS - 1973 DATA
(mg/l except pH.)

Run No.	BOD	Suspended Solids	Volatile suspended solids	Kjeldahl nitrogen	pH	Total solids	Total volatile solids	Total phosphate	Coliform per ml	TOC	DOC
73-1	24	116	38	3.70	7.2	224	109	0.70	430,000	32	11
73-2	61	276	86	5.85	7.1	395	143	2.47	6,500	64	29
73-3	69	133	49	3.50	7.3	269	121	0.75	400	41	32
73-4	24	81	75	3.00	7.5	201	92	0.98	10,700	24	12
73-5	80	205	93	7.80	7.1	363	176	1.52	34,500	69	34
73-6	16	39	16	2.00	7.4	211	89	0.85	21,700	18	12
73-7	69	247	77	14.30	7.1	420	189	--	1,960	79	15
73-8	11	58	28	2.60	7.3	145	34	0.43	3,800	10	7
73-9	53	93	51	3.90	6.9	210	86	0.95	156,000	44	12
73-10	11	39	12	1.90	7.4	112	41	0.25	18,662	13	9

Table E-25. SCREENED WATER QUALITY EXTENDED OVERFLOW - 1973 DATA
(mg/1 except pH.)

No.	BOD	Suspended solids	Volatile suspended solids	pH	Total solids	Total volatile solids	TOC
73-1	24	116	38	7.2	224	109	32
73-2	51	265	75	6.5	424	160	56
73-3	63	145	42	6.7	285	140	38
73-4	22	62	47	7.3	189	89	22
73-5	74	171	63	7.4	357	162	64
73-6	--	--	--	--	--	--	--
73-7	40	198	56	5.9	432	157	56
73-8	11	45	19	7.0	155	31	10
73-9	26	64	31	7.2	195	74	28
73-10	14	68	21	6.3	164	64	14

Table E-26. EFFLUENT WATER QUALITY EXTENDED OVERFLOW - 1973 DATA - LOW OVERFLOW RATES
(mg/l except pH and coliform.)

No.	BOD	Suspended solids	Volatile suspended solids	Kjeldahl nitrogen	pH	Total solids	Total volatile solids	Total phosphate	Coliform per ml	TOC	DOC
73-1	13	42	19	6.1	7.10	237	97	0.45	38,000	20	17
73-2	26	62	25	4.0	6.75	205	83	0.77	3,200	26	25
73-3	39	38	21	3.0	7.02	187	98	0.32	500	24	--
73-4	27	65	31	2.9	7.25	182	86	0.51	12,600	26	14
73-5	21	104	37	12.9	7.42	366	198	0.81	23	71	37
73-6	--	--	--	--	--	--	--	--	--	--	--
73-7	18	80	17	3.7	6.12	312	137	--	870	27	10
73-8	8	26	14	2.6	6.75	138	36	0.25	8,200	8	5
73-9	17	29	22	3.1	7.02	146	50	0.52	63,000	16	8
73-10	8	18	5	1.0	6.65	97	34	0.16	8,500	9	7

Table E-27. EFFLUENT WATER QUALITY - EXTENDED OVERFLOW - 1973 DATA - HIGH OVERFLOW RATES
(mg/1 except pH and coliform.)

Run No.	BOD	Suspended solids	Volatile suspended solids	Kjeldahl nitrogen	pH	Total solids	Total volatile solids	Total phosphate	TOC
73-1	14	44	14	5.80	7.20	249	94	0.44	18
73-2	22	52	22	3.55	6.75	199	83	1.27	23
73-3	36	34	17	3.00	7.10	193	95	0.25	29
73-4	28	62	30	--	7.38	196	94	0.59	23
73-5	47	124	45	--	7.45	267	127	0.98	44
73-6	--	--	--	--	--	--	--	--	--
73-7	19	108	29	1.60	7.05	317	137	--	31
73-8	8	17	5	2.40	6.95	133	34	0.28	8
73-9	17	34	10	--	7.12	148	46	0.53	11
73-10	6	24	1	0.60	6.65	113	34	0.17	10

Table E-28. FLOATED SCUM QUALITY - 1973 DATA
(mg/l except pH and coliform)

	Floated Scum Quality		
Run #	Total solids	Total volatile solids	Suspended solids[a]
73-1	34500	9760	--
73-2	15700	5550	15581
73-3	258500	6400	258364
73-4	8539	2672	8419
73-5	16600	6895	16442
73-6	--	--	--
73-7	37996	12613	37823
73-8	14857	5881	14770
73-9	10298	4415	10181
73-10	15845	6940	

a. Calculated based on dissolved solids in raw waste.

Table E-29. EXTENDED OVERFLOW REMOVALS IN PERCENT - 1973 DATA - HIGH OVERFLOW RATES

	Overall System					
Run No.	TOC	BOD	SS	VSS	Total phosphate	Kjeldahl nitrogen
73-1	52.3	--	68.4	71.2	--	--
73-2	64.1	63.9	81.2	74.4	48.6	39.3
73-3	57.1	43.5	71.4	57.1	57.3	14.3
73-4	4.2	--	23.5	60.0	39.8	--
73-5	36.2	41.3	39.5	51.6	35.5	--
73-6	--	--	--	--	--	--
73-7	60.8	72.5	56.3	62.3	--	--
73-8	20.0	27.3	70.7	82.1	34.9	7.7
73-9	75.0	67.9	63.4	80.4	44.2	--
73-10	41.2	--	70.7	96.3	--	--

Table E-30. EXTENDED OVERFLOW REMOVALS IN PERCENT - 1973 DATA - LOW OVERFLOW RATES

	Screen				Overall System					
Run No.	TOC	BOD	SS	VSS	TOC	BOD	SS	VSS	Total phosphate	Kjeldahl nitrogen
73-1	--	--	--	--	47.0	--	69.8	60.9	--	--
73-2	12.5	16.4	4.0	12.8	59.4	57.4	77.5	70.9	31.8	68.8
73-3	14.3	8.7	--	14.3	65.3	47.8	74.4	65.3	14.3	66.7
73-4	8.3	8.3	23.5	37.3	--	--	19.8	60.0	3.3	48.0
73-5	7.3	7.5	16.6	32.3	--	73.8	49.3	60.2	--	46.7
73-6	--	--	--	--	--	--	--	--	--	--
73-7	29.1	42.0	19.8	27.3	65.8	73.9	67.6	77.9	74.1	--
73-8	--	--	22.4	32.1	20.0	27.3	55.2	50.0	--	41.9
73-9	36.3	50.9	31.1	39.2	63.6	67.9	68.8	56.9	20.5	45.3
73-10	--	--	--	--	47.1	--	78.1	81.5	--	--

Table E-31. OPERATIONAL RESULTS FOR HAWLEY ROAD TREATMENT FACILITY

Run No.	1
Date	August 2, 1974
Duration of Run, min.	88.8
Total Volume Treated, cu m (gal.)	458 (120,960)
Recycle Rate, %	45.9
Flow Rates, l/min (gpm)	
Raw	5155 (1362)
Recycle	2366 (625)
Total	7521 (1987)
Overflow Rate, l/min/sq m (gpm/sq ft)	
Raw	71 (1.75)
Total	104 (2.55)
Chemical Dosages, mg/l	
Alum	19
Carbon	94
Betz 1160	1.4

				Percent Removal		
Quality Parameters	Raw	Screened Effluent	Final Effluent	Screen	Flotation	Total
pH						
SS, mg/l	96	72	17	25.0	76.3	82.2
VSS, mg/l						
TS, mg/l	321	240	365	25.2	(52.0)	(13.7)
TVS, mg/l						
BOD, mg/l	21	23	10	(9.5)	56.5	52.3
TOC, mg/l	19	12	13	36.8	(8.3)	31.5
SOC, mg/l	12	14	11	(16.6)	21.4	8.3
Total P, mg/l as P	0.61	0.62	0.33	(1.6)	46.7	45.9

Note: Numbers in parentheses represent an increase in concentration.

Table E-32. OPERATIONAL RESULTS FOR HAWLEY ROAD TREATMENT FACILITY

Run No.	2
Date	August 10, 1974
Duration	70
Total Volume Treated, cu m (gal.)	486 (128,520)
Recycle Rate, %	34.0
Flow Rates, l/min (gpm)	
Raw	6949 (1836)
Recycle	2366 (625)
Total	9315 (2461)
Overflow Rate, l/min/sq m (gpm/sq ft)	
Raw	96 (2.35)
Total	129 (3.16)
Chemical Dosages, mg/l	
Alum	30
Carbon	46
Betz 1160	1.7

				Percent Removal		
Quality Parameters	Raw	Screened Effluent	Final Effluent	Screen	Flotation	Total
pH	7.35	7.35	7.25			
SS, mg/l	134	124	34	7.4	72.5	74.6
VSS, mg/l	84	77	9	8.3	88.3	89.2
TS, mg/l	333	280	519	15.9	(85.3)	(55.8)
TVS, mg/l	175	169	233	3.4	(37.8)	(33.1)
BOD, mg/l	34	29	6	14.7	79.3	82.3
TOC, mg/l	29	29	10	0.0	65.5	65.5
SOC, mg/l	26	28	9	(7.6)	67.8	65.3
Total P, mg/l as P	1.66	0.72	0.19	56.6	73.6	88.5

Note: Numbers in parentheses represent an increase in concentration.

Table E-33. OPERATIONAL RESULTS FOR HAWLEY ROAD TREATMENT FACILITY

Run No.	3
Date	August 16, 1974
Duration of Run, min.	140
Total Volume Treated, cu m (gal.)	963 (254,520)
Recycle Rate, %	30.3
Flow Rates, l/min (gpm)	
Raw	6881 (1818)
Recycle	2082 (550)
Total	8963 (2368)
Overflow Rate, l/min/sq m (gpm/sq ft)	
Raw	95 (2.33)
Total	124 (3.04)
Chemical Dosages, mg/l	
Alum	63
Carbon	60
Betz 1160	0.45

				Percent Removal		
Quality Parameters	Raw	Screened Effluent	Final Effluent	Screen	Flotation	Total
pH	7.3	7.0	6.9			
SS, mg/l	131	183	30	(39.6)	83.6	77.0
VSS, mg/l	43	62	8	(44.1)	87.0	81.3
TS, mg/l	612	443	398	27.6	10.1	34.9
TVS, mg/l	189	153	139	19.0	9.1	26.4
BOD, mg/l	64	55	22	14.0	60.0	65.6
TOC, mg/l	36	48	20	(33.3)	58.3	44.4
SOC, mg/l	12	8	11	33.3	(37.5)	8.3
Total P, mg/l as P	1.02	1.25	0.19	(22.5)	84.8	81.3

Note: Numbers in parentheses represent an increase in concentration.

Table E-34. OPERATIONAL RESULTS FOR HAWLEY ROAD TREATMENT FACILITY

Run No.		4
Date		August 26, 1974
Duration of Run, min.		63
Total Volume Treated, cu m (gal.)	496	(131,040)
Recycle Rate, %		23.9
Flow Rates, l/min. (gpm)		
Raw	7911	(2090)
Recycle	1892	(500)
Total	9803	(2590)
Overflow Rate, l/min/sq m (gpm/sq ft)		
Raw	109	(2.68)
Total	135	(3.32)
Chemical Dosages, mg/l		
Alum		57
Carbon		43
Betz 1160		0.43

Quality Parameters	Raw	Screened Effluent	Final Effluent	Percent Removal Screen	Flotation	Total
pH	6.95	5.85	6.30			
SS, mg/l	57	68	48	(19.2)	29.4	15.7
VSS, mg/l	19	17	20	10.5	(17.6)	(5.2)
TS, mg/l	180	226	200	(25.5)	11.5	(11.1)
TVS, mg/l	147	187	187	(27.2)	0.0	(27.2)
BOD, mg/l	26	23	10	11.5	56.5	61.5
TOC, mg/l	22	19	11	13.6	42.1	50.0
SOC, mg/l	14	12	7	14.2	41.6	50.0
Total P, mg/l as P	1.19	1.61	0.21	(35.2)	86.9	82.3

Note: Numbers in parentheses represent an increase in concentration.

Table E-35. OPERATIONAL RESULTS FOR HAWLEY ROAD TREATMENT FACILITY

Run No.	5
Date	September 12, 1974
Duration of Run, min.	105
Total Volume Treated, cu m (gal.)	763 (201,600)
Recycle Rate, %	26.1
Flow Rates, l/min (gpm)	
Raw	7244 (1914)
Recycle	1892 (500)
Total	9136 (2414)
Overflow Rate, l/min/sq m (gpm/sq ft)	
Raw	100 (2.45)
Total	126 (3.09)
Chemical Dosages, mg/l	
Alum	45
Carbon	42
Betz 1160	0.54

				Percent Removal		
Quality Parameters	Raw	Screened Effluent	Final Effluent	Screen	Flotation	Total
pH	7.1	7.1	7.1			
SS, mg/l	254	320	70	(26.0)	78.1	72.4
VSS, mg/l	130	170	34	(30.8)	80.0	73.8
TS, mg/l	822	759	664	7.7	12.5	19.2
TVS, mg/l	340	312	271	8.2	13.1	20.3
BOD, mg/l	90	92	18	(2.2)	80.4	80.0
TOC, mg/l	84	86	41	(2.4)	52.3	51.2
SOC, mg/l	37	48	25	(29.7)	47.9	32.4
Total P, mg/l as P	1.92	1.91	0.53	0.5	72.2	72.4

Note: Numbers in parentheses represent an increase in concentration.

Table E-36. OPERATIONAL RESULTS FOR HAWLEY ROAD TREATMENT FACILITY

Run No.	6
Date	September 28, 1974
Duration of Run, min.	147
Total Volume Treated, cu m (gal.)	1249 (330,088)
Recycle Rate, %	28.6
Flow Rates, l/min. (gpm)	
Raw	6609 (1746)
Recycle	1892 (500)
Total	8501 (2246)
Overflow Rate, l/min/sq m (gpm/sq ft)	
Raw	91 (2.23)
Total	117 (2.87)
Chemical Dosages, mg/l	
Alum	45.8
Carbon	45.8
Betz 1160	0.95

Quality Parameters	Raw	Screened Effluent	Final Effluent	Percent Removal Screen	Percent Removal Flotation	Percent Removal Total
pH	6.7	6.4	6.95			
SS, mg/l	168	146	15	13.1	89.7	91.1
VSS, mg/l	48	56	4	(16.7)	92.8	91.7
TS, mg/l	373	282	169	24.4	40.1	54.7
TVS, mg/l	259	183	149	29.3	18.6	42.5
BOD, mg/l	62	44	10	29.0	77.3	83.9
TOC, mg/l	56	54	15	3.6	72.2	73.2
SOC, mg/l	36	23	11	36.1	52.2	69.4
Total P, mg/l as P	1.7	1.1	0.2	35.3	81.8	88.2

Note: Numbers in parentheses represent an increase in concentration.

Table E-37. OPERATIONAL RESULTS FOR HAWLEY ROAD TREATMENT FACILITY

Run No	7
Date	October 6, 1974
Duration	100
Total Volume Treated, cu m (gal.)	900 (236,400)
Recycle Rate, %	26.3
Flow Rates, l/min (gpm)	
Raw	7055 (1864)
Recycle	1892 (500)
Total	8947 (2364)
Overflow Rate, l/min/sq m (gpm/sq ft)	
Raw	97 (2.39)
Total	123 (3.03)
Chemical Dosages, mg/l	
Alum	18 (pump malfunctioned)
Carbon	0
Betz 1160	1.1

				Percent Removal		
Quality Parameters	Raw	Screened Effluent	Final Effluent	Screen	Flotation	Total
pH	6.8	6.4	6.2			
SS, mg/l	42	49	29	(16.7)	40.8	31.6
VSS, mg/l	19	25	15	(21.6)	40.0	21.0
TS, mg/l	114	117	93	(2.6)	20.5	18.4
TVS, mg/l	32	17	47	47.0	(176.0)	(46.9)
BOD, mg/l	15	15	14	0.0	6.7	6.7
TOC, mg/l	18	20	13	11.1	35.0	27.8
SOC, mg/l	13	10	10	23.1	0.0	23.1
Total P, mg/l as P	0.44	0.25	0.25	(4.5)	45.6	43.2

Note: Numbers in parentheses represent an increase in concentration.

Table E-38. OPERATIONAL RESULTS FOR HAWLEY ROAD TREATMENT FACILITY

Run No.	8
Date	October 13, 1974
Duration of Run, min.	135
Total Volume Treated, cu m (gal.)	1002 (264,600)
Recycle Rate, %	35.6
Flow Rates, l/min (gpm)	
Raw	7434 (1964)
Recycle	2650 (700)
Total	10084 (2664)
Overflow Rate, l/min/sq m (gpm/sq ft)	
Raw	102 (2.51)
Total	139 (3.41)
Chemical Dosages, mg/l	
Alum	33
Carbon	43
Betz 1160	0.74

Quality Parameters	Raw	Screened Effluent	Final Effluent	Percent Removal Screen	Flotation	Total
pH	6.7	6.6	6.7			
SS, mg/l	74	91	59	(22.4)	35.1	20.2
VSS, mg/l	42	50	33	(19.0)	34.0	21.4
TS, mg/l	152	156	131	(2.6)	16.0	13.8
TVS, mg/l	84	86	66	(2.3)	23.2	21.4
BOD, mg/l	37	38	20	(2.7)	47.3	45.9
TOC, mg/l	33	40	28	(21.2)	45.0	33.0
SOC, mg/l	17	17	13	0.0	23.5	23.5
Total P, mg/l as P	0.85	0.92	0.54	(8.2)	41.3	36.4

Note: Numbers in parentheses represent an increase in concentration.

Table E-39. OPERATIONAL RESULTS FOR HAWLEY ROAD TREATMENT FACILITY

Run No.	9
Date	October 29, 1974
Duration of Run, min.	100
Total Volume Treated, cu m (gal.)	857 (226,480)
Recycle Rate, %	21.4
Flow Rates, l/min (gpm)	
Raw	7059 (1865)
Recycle	1514 (400)
Total	8573 (2265)
Overflow Rate, l/min/sq m (gpm/sq ft)	
Raw	97 (2.39)
Total	118 (2.90)
Chemical Dosages, mg/l	
Alum	18.5 (pump malfunctioned)
Carbon	25.6
Betz 1160	1.23

Quality Parameters	Raw	Screened Effluent	Final Effluent	Percent Removal Screen	Percent Removal Flotation	Percent Removal Total
pH	6.8	6.8	6.7			
SS, mg/l	523	170	170	67.5	0.0	67.5
VSS, mg/l	303	100	106	66.9	(6.0)	65.0
TS, mg/l	885	456	402	48.4	11.8	54.5
TVS, mg/l	503	274	282	45.5	(2.9)	43.9
BOD, mg/l	318	135	118	57.5	12.6	62.8
TOC, mg/l	213	96	114	54.9	(20.8)	46.4
SOC, mg/l	53	44	39	16.9	11.3	26.4
Total P, mg/l as P	4.04	2.18	1.66	46.0	23.8	58.9

Note: Numbers in parentheses represent an increase in concentration.

Table E40. OPERATIONAL RESULTS FOR HAWLEY ROAD TREATMENT FACILITY

Run No.	10
Date	October 29, 1974
Duration of Run, min.	104
Total Volume Treated, cu m (gal.)	106 (281,320)
Recycle Rate, %	22.7
Flow Rates, l/min (gpm)	
Raw	8346 (2205)
Recycle	1892 (500)
Total	10238 (2705)
Overflow Rate, l/min/sq m (gpm/sq ft)	
Raw	115 (2.82)
Total	141 (3.46)
Chemical Dosages, mg/l	
Alum	21.7 (pump malfunctioned)
Carbon	46.8
Betz 1160	0.11 (pump malfunctioned)

Quality Parameters	Raw	Screened Effluent	Final Effluent	Percent Removal Screen	Percent Removal Flotation	Percent Removal Total
pH	6.7	6.8	7.0			
SS, mg/l	140	102	82	27.1	19.6	41.4
VSS, mg/l	95	58	68	38.9	(17.2)	28.4
TS, mg/l	296	260	273	12.1	(5.0)	7.7
TVS, mg/l	192	180	173	6.25	3.9	9.8
BOD, mg/l	74	57	36	23.0	36.0	51.3
TOC, mg/l	69	54	49	21.7	9.2	28.9
SOC, mg/l	34	27	21	20.5	22.2	38.2
Total P, mg/l as P.	1.27	1.18	0.83	7.0	29.6	34.6

Note: Numbers in parentheses represent an increase in concentration.

Table E-41. OPERATING CONDITIONS FOR THE SERIES SCREENING SYSTEM

Run #	Date	Feed flow, gpm	Length of run (min)	Raw flow volume (1,000 gal.)	Hydraulic loading[a], gpm/sq ft		
					Screen 1[b]	Screen 2[c]	Screen 3[d]
71-01	5/25/71	3300	30	66.55	43.4	26.8	26.8
71-02	6/02/71	3295	59	194.05	43.25	26.7	26.7
71-03	6/11/71	3273	30	98.20	43.1	26.6	26.6
71-04	6/12/71	3225	31.8	102.40	42.5	26.25	26.25
71-05	6/18/71	3240	106.5	344.20	42.6	26.35	26.35
71-06	6/19/71	3270	56.7	185.5	43.0	26.6	26.6
71-07	6/20/71	3300	143	472.0	43.4	26.8	26.8
71-08	6/22/71	3280	64	210.0	43.2	26.65	26.65
71-09	7/08/71	3540	70	248.6	46.6	28.8	28.8
71-10	7/19/71	3100	50	155.6	40.8	25.2	25.2
71-11	8/02/71	2740	85	233.2	36.1	22.3	22.3
71-12	8/10/71	1850	57	105.7	24.3	15.0	15.0
71-13	8/14/71	1795	46	82.5	23.6	14.6	14.6
71-14	8/14/71	1835	82.6	151.15	24.1	14.9	14.9
71-15	8/20/71	1870	35	65.65	24.6	15.2	15.2
71-16	8/22/71	1870	37	69.10	24.6	15.2	15.2
71-17	9/25/71	2100	55	114.40	27.6	17.1	17.1
71-18	9/27/71	2300	49	113.00	30.2	18.7	18.7
71-19	10/03/71	2300	95	217.80	30.2	18.7	18.7
71-20	10/19/71	2210	54.4	120.10	29.1	18.0	18.0
71-21	11/01/71	2360	120.2	283.6	31.1	19.2	19.2

[a] Wetted area at maximum headloss
Screen 1: 76 sq ft
Screen 2 & 3: 123 sq ft

[b] Screen opening: 841 Microns (20 mesh)

[c] Screen opening: 149 Microns (100 mesh)

[d] Screen opening: 63 Microns (230 mesh)

Table E-41. (Continued)
OPERATING CONDITIONS FOR THE SERIES SCREENING SYSTEM

Run	Backwash volumes, gallons			Drum speed, rpm			Chemical dosages, mg/1	
#	Screen 1	Screen 2	Screen 3	Screen 1	Screen 2	Screen 3	Cl_2	Nalco 607
71-01	6,325	10	2,060	6.5	6.9	5.0	0	0
71-02	0	5	155	5.8	5.3	5.2	0	0
71-03	875	3,905	2,270	5.8	5.3	5.2	0	0
71-04	290	370	635	4.4-7.6	5.3	5.2	0	0
71-05	1,570	1,685	4,840	4.4	5.3	5.2	7.5	0
71-06	900	150	1,830	4.4	5.3	5.2	7.5	0
71-07	0	670	0	4.4	5.3	5.2	7.5	0
71-08	1.170	685	2,505	4.4	3.5-4.6	3.4-4.9	0	0
71-09	20	1,460	4,080	4.45	4.6	4.85	7.5	4.5[a]
71-10	3,530	5,810	1.770	4.45-6.7	4.6	4.85	0	0
71-11	420	2,060	1.630	6.7-2.05	4.6-1.5	4.85-1.9	5.0	0
71-12	140	640	820	2.05	1.5	1.4	10.3	0
71-13	250	190	360	2.05	1.5	1.4	11.0	0
71-14	30	350	270	2.05	1.5	1.4-2.55	11.0	0
71-15	190	420	420	5.8	4.0	4.4	15.0	0
71-16	40	110	70	5.8	4.0	4.4	17.0	0
71-17	300	3,190	3,350	5.8	4.0	3.85	0	
71-18	180	1,500	1,160	5.8	4.0	3.85	0	5.25
71-19	9,080	1,900	7.180	5.8	4.0	4.4	9.0	5.25
71-20	0	120	300	5.8	4.0	4.4	6.7	5.0
71-21	930	1,900	2,090	5.8	4.0	4.4	10.0	5.0

a. Cationic polyelectrolyte C31 used for this storm.

Table E-42. RAW WASTE CHARACTERISTICS
(mg/l except pH.)

Run No.	pH	Total solids	Total volatile solids	Suspended solids	Volatile suspended solids	TOC
71-01	7.45	840	354	728	172	93
71-02	7.3	365	242	206	40	41
71-03	--	1,514	720	1,025	437	260
71-04	7.05	627	262	322	230	73
71-05	7.30	778	300	560	161	35
71-06	6.95	437	138	437	138	41
71-07	7.20	237	104	78	22	12
71-08	7.0	782	158	556	141	64
71-09	6.9	542	229	330	88	27
71-10	7.06	1,279	551	886	366	194
71-11	7.5	422	179	313	96	38
71-12	7.2	494	219	188	89	85
71-13	6.70	437	195	229	87	57
71-14	7.10	255	115	138	27	18
71-15	7.10	567	289	303	181	112
71-16	7.05	620	485	580	112	69
71-17	7.6	--	--	1,074	188	80
71-18	7.42	548	216	336	148	62
71-19	7.4	355	182	349	126	36
71-20	7.5	688	260	293	112	82
71-21	6.9	315	140	204	104	46

Table E-42. (Continued)

RAW WASTE CHARACTERISTICS
(mg/1 except Coliform density.)

Run No.	COD	BOD	Dissolved TOC	Total Nitrogen	Ortho Phosphate as P	Coliform density per ml
71-01	260	--	23	--	--	--
71-02	120	36	18	3.9	.45	100
71-03	904	295	70	27.9	.93	540,000
71-04	224	54	27	5.45	.30	55,000
71-05	142	44	17	4.2	.18	31,000
71-06	123	41	15	4.0	.13	115,000
71-07	26	4	6	1.0	.12	6,000
71-08	161	28	10	4.2	.06	8,000
71-09	74	19	14	2.0	.07	490
71-10	428	129	32.5	12.4	.23	84,000
71-11	94	16	15	2.53	.08	3,600
71-12	219	92	45	7.5	.41	6,500
71-13	143	49	23	4.6	.20	34,000
71-14	44	6	9	1.15	.08	140
71-15	339	139	35	14.0	.73	380,000
71-16	154	27	13	3.30	.09	128,000
71-17	210	47	18	6.0	.16	6,500
71-18	182	46	14	6.0	.16	--
71-19	78	24	13	2.4	.22	6,800
71-20	334	132	43	9.5	.70	9,000
71-21	125	44	15	3.4	--	21,000

Table E-43. SCREENED WATER QUALITY - DRUM SCREEN 1 (20 MESH)

(mg/1 except pH.)

Run No.	pH	Total solids	Total volatile solids	Suspended solids	Volatile suspended solids	TOC	COD	BOD	Dissolved TOC
71-01	--	--	--		--	--	--	--	--
71-02	7.3	352	204	217	53	28	109	26	15
71-03	--	--	--	--	--	--	--	--	--
71-04	7.1	864	363	492	284	96	274	58	21
71-05	7.7	749	313	553	121	37	154	28	15
71-06	7.3	489	131	413	145	35	93	--	--
71-07	7.4	212	107	67	11	13	26	--	--
71-08	7.3	464	174	385	107	52	152	--	8
71-09	7.3	468	203	300	70	31	75	14	15
71-10	7.1	821	294	554	144	49	218	86	38
71-11	7.6	378	171	256	49	37	84	16	11
71-12	7.4	526	235	160	74	95	225	69	58
71-13	7.3	418	184	192	58	56	140	40	29
71-14	7.0	248	109	137	36	22	46	10	10
71-15	7.4	651	198	263	146	108	327	147	45
71-16	7.1	528	263	528	102	51	128	20	14
71-17	7.7	--	--	991	150	73	205	38	12
71-18	7.5	496	207	273	121	54	179	44	14
71-19	7.5	416	178	252	107	33	80	24	17
71-20	7.7	734	288	244	100	84	347	134	43
71-21	7.2	344	135	151	60	44	103	39	21

Table E-44. SCREENED WATER QUALITY - DRUM SCREEN 2 (100 MESH)
(mg/1 except pH.)

Run No.	pH	Total solids	Total volatile solids	Suspended solids	Volatile suspended solids	TOC	COD	BOD	Dissolved TOC
71-01	7.3	740	279	523	133	77	193	--	26
71-02	7.1	401	309	107	25	29	76	30	20
71-03	--	1220	581	730	440	210	577	236	--
71-04	7.1	680	263	318	208	65	167	46	17
71-05	7.7	721	274	487	125	44	138	25	17
71-06	7.2	524	156	385	99	35	97	--	--
71-07	7.4	212	123	66	17	12	39	4	8
71-08	7.3	480	181	362	170	46	147	--	8
71-09	7.7	491	211	251	53	28	69	13	15
71-10	7.2	686	253	472	138	38	165	77	37
71-11	7.8	348	155	253	54	29.5	71	10	14
71-12	7.4	512	226	153	63	84	213	80	51
71-13	7.4	399	187	164	53	52	132	37	26
71-14	7.1	234	98	130	35	19	39	7	10
71-15	7.5	561	296	256	130	103	328	147	46
71-16	--	--	--	--	--	--	--	--	--
71-17	7.8	--	--	1019	145	63	187	16	15
71-18	7.6	460	187	257	102	53	151	42	14
71-19	7.5	416	178	252	107	33	80	24	19
71-20	7.8	690	243	229	106	79	310	135	44
71-21	7.5	348	154	184	77	43	119	44	23

Table E-45. SCREENED WATER QUALITY - DRUM SCREEN 3 (230 MESH)
(mg/l except pH.)

Run No.	pH	Total solids	Total volatile solids	Suspended solids	Volatile suspended solids	TOC
71-01	7.3	546	209	426	104	42
71-02	7.2	344	200	123	16	25
71-03	--	999	442	533	395	159
71-04	7.1	582	209	316	216	56
71-05	7.8	554	280	364	96	30
71-06	7.4	408	119	355	98	36
71-07	--	--	--	--	--	14
71-08	7.1	634	82	366	78	37
71-09	8.0	470	197	303	55	27
71-10	7.2	657	236	544	126	55
71-11	7.8	356	147	257	51	32
71-12	7.4	505	216	132	67	85
71-13	7.2	383	206	183	57	51
71-14	7.1	186	85	85	27	15
71-15	6.9	559	256	273	143	85
71-16	7.3	599	205	508	86	51
71-17	7.8	--	--	841	101	50
71-18	7.6	447	202	243	96	44
71-19	7.5	369	188	204	83	34
71-20	7.8	664	259	263	114	82
71-21	7.5	317	133	152	68	45

Table E-45. (Continued)
SCREENED WATER QUALITY - DRUM SCREEN 3 (230 MESH)
(mg/1 except Coliform density.)

Run No.	COD	BOD	Dissolved TOC	Total nitrogen	Ortho phosphate as P	Coliform density per ml
71-01	159	--	21	--	--	--
71-02	63	22	16	2.5	0.31	100
71-03	507	181	74	19.3	1.13	200,000
71-04	147	45	22	4.8	0.3	25,000
71-05	96	26	20	3.4	0.22	54
71-06	94	30	18	3.6	0.32	<1
71-07	--	--	--	1.0	0.12	<1
71-08	110	20	10	3.3	0.06	3,000
71-09	72	15	17	2.3	0.09	0
71-10	195	85	30.5	5.9	0.24	49,500
71-11	78	13	15	1.7	0.13	<50
71-12	208	72	60	8.2	0.55	2,178
71-13	127	38	27	4.1	0.36	6
71-14	36	6	10	0.6	0.13	3
71-15	--	97	46	--	--	3
71-16	105	15	14	3.0	0.11	2
71-17	182	29	15	4.3	0.04	4,500
71-18	142	36	14	5.4	0.38	--
71-19	75	20	15	5.4	0.29	<1
71-20	312	135	46	9.5	0.76	100
71-21	111	43	23	3.7	--	<1

Table E-46. SCREEN BACKWASH QUALITY

Run No.	pH, units			Total solids, mg/l			Total volatile solids, mg/l		
	Screen 1	Screen 2	Screen 3	Screen 1	Screen 2	Screen 3	Screen 1	Screen 2	Screen 3
71-01									
71-02									
71-03									
71-04	--	7.1	7.1	--	2804	--	--	2175	--
71-05	7.0	7.8	7.8	2846	2018	1680	1783	868	597
71-06	7.1	7.4	7.6	4932	3008	2853	2925	1230	624
71-07	7.3	7.1	7.4	452	422	469	261	252	224
71-08	7.3	7.7	7.7	4726	3472	2295	3113	1615	1823
71-09	7.0	7.7	8.3	3193	1892	2983	2309	833	740
71-10	7.1	7.3	7.3	4496	4997	3302	2516	1982	690
71-11	8.2	8.4	8.5	7937	3502	1769	4151	1640	649
71-12	7.4	7.4	7.6	4400	1857	880	3236	1098	450
71-13	7.5	7.5	7.6	490	615	958	289	337	516
71-14	--	--	--	--	--	--	--	--	--
71-15	7.2	7.2	7.4	2076	2178	804	1179	1557	486
71-16	--	--	--	1613	2144	1264	1141	1125	245
71-17	7.8	7.8	7.6	--	--	--	--	--	--
71-18	7.4	7.4	7.7	1172	8045	1110	765	5512	556
71-19	--	--	--	--	--	--	--	--	--
71-20	--	--	--	--	--	--	--	--	--
71-21	8.4	8.8	8.7	3655	3227	1796	2697	2297	852

Table E-47. OPERATING CONDITIONS FOR THE MICROSCREENING SYSTEM

Run #	Date	Feed flow, gpm	Length of run, min.	Raw flow volume, gal.	Screen hyd.load, gpm/sq ft	Average headloss, inch H_2o	Drum speed, rpm	Backwash volume, gal.
73-1	7/19/73	1687	69.2	116,718	27.10	13.0	3.8	--
73-2	7/26/73	1704	51.6	87,948	27.48	12.75	3.8	--
73-3	8/8/73	1959	38.3	115,788	34.07	12.95	3.8	3980
73-4	8/9/73	2371	30.7	79,438	40.96	13.00	3.8	3195
73-5	9/4/73	2384	44.7	106,587	37.50	<14.00	3.8-5.8	3655
73-6	9/17/73	1647	70.2	115,619	27.45	10.00	5.8	6420
73-7	9/24/73	1007	29.5	29,700	15.79	15.00	5.8	2604
73-8a	9/28/73	767	34.3	26,313	12.66	12.50	5.8	3065
73-8b	9/28/73	1225	82.6	104,542	20.59	9.00	5.8	7270
73-9	10/1/73	1420	32.2	39,480	23.10	13.20	5.8	2690
73-10	10/4/73	895	30.4	27,204	14.55	12.00	5.8	2755

Table E-48. MICROSCREENING TREATMENT OF FLOTATION EFFLUENT (RAW WASTE CHARACTERISTICS)
(mg/l except pH)

Run No.	pH	Total Solids	Total Volatile Solids	Suspended Solids	Volatile Suspended Solids	TOC	BOD	Total Phosphate	Kjeldahl Nitrogen
73-1	7.15	233	96	43	17	19	14	0.45	5.95
73-2	6.75	202	83	57	24	25	24	1.02	3.77
73-3	7.06	190	97	36	19	27	38	0.29	3.00
73-4	7.33	189	90	64	31	25	28	0.55	2.90
73-5	7.44	317	163	114	41	58	58	0.90	12.90

Table E-49. MICROSCREENED WATER QUALITY
(FLOTATION EFFLUENT TREATMENT)
(mg/l except pH)

Run No.	pH	Total Solids	Total Volatile Solids	Suspended Solids	Volatile Suspended Solids	TOC	BOD	Total Phosphate	Kjeldahl Nitrogen
73-1	7.10	268	105	30	14	21	15	.42	5.70
73-2	6.85	209	80	31	11	22	16	.54	3.96
73-3	6.92	208	117	34	17	24	35	.24	2.50
73-4	7.18	155	66	58	32	23	31	.42	2.50
73-5	7.40	266	124	76	11	28	38	.75	5.90

Table E-50. MICROSCREENING TREATMENT OF RAW CSO (RAW WASTE CHARACTERISTICS) (mg/l except pH)

Run No.	pH	Total Solids	Total Volatile Solids	Suspended Solids	Volatile Suspended Solids	TOC	BOD	Total Phosphate	Kjeldahl Nitrogen	DOC
73-6	7.35	211	89	39	16	18	16	.85	2.0	12
73-7	7.05	420	189	247	77	79	69	--	14.3	15
73-8a	7.32	720	466	80	48	139	5	.51	58.6	175
73-8b	--	--	--	81	--	--	--	--	--	--
73-9	6.98	221	116	95	75	47	64	.89	4.5	12
73-10	7.35	112	41	39	12	13	11	.25	1.9	9

Table E-51. MICROSCREENED WATER QUALITY (RAW CSO TREATMENT)
(mg/l except pH)

Run No.	pH	Total Solids	Total Volatile Solids	Suspended Solids	Volatile Suspended Solids	TOC	BOD	Total Phosphate	Kjeldahl Nitrogen	DOC
73-6	7.40	198	63	48	34	21	15	.88	2.7	11
73-7	7.10	300	152	127	38	43	35	--	4.4	--
73-8a	7.32	153	35	43	16	14	14	.44	2.4	7
73-8b	--	--	--	66	--	--	--	.76	--	--
73-9	7.10	132	58	51	40	32	33	.44	3.7	11
73-10	7.15	118	48	48	19	19	20	--	1.7	14

STATISTICAL PROCEDURES

The following statistical procedures were utilized:

Estimate of a Mean Value

$$x = \overline{x} \pm \frac{ts}{\sqrt{n}}$$

where: x - estimated mean value

$\overline{x}$ = mean of n values

t = student "t" value at n-1 degrees of freedom for some confidence level

s = standard deviation of the data points

n = number of pieces of data

Comparison of Means Test

1. Perform "F" test

$$F_c = \frac{s_1^2}{s_2^2}$$

If: $F_c < F_t$ go to step 2
If: $F_c > F_t$ go to step 3
F_t = Table "F" value
F_c = calculated "F" value
s_1 = standard deviation of first set of data
s_2 = standard deviation of second set of data

2. Comparison of means "t" test when:

$$\sigma_1^2 = \sigma_2^2$$

$$s = \sqrt{\frac{\Sigma(x_1)^2 - ((\Sigma x_1)^2/n_1) + \Sigma(x_2)^2 - ((\Sigma x_2)^2/n)}{n_1 + n_2 - 2}}$$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(1/n_1) + (1/n_2)}}$$

Degrees of freedom (DF) = $n_1 + n_2 - 2$

Read "t" table at t and DF to find confidence level at which a difference exists.

3. Comparison of means "t" test when

$$\sigma_1^2 \neq \sigma_2^2$$

$$S\bar{x}_1^2 = (S_1)^2/n_1$$

$$S\bar{x}_2^2 = (S_2)^2/n_2$$

Complete DF (ν) from:

$$1/\nu = (1/\nu_1)\ ((S\bar{x}_1^2)/(S\bar{x}_1^2 + S\bar{x}_2^2))^2 + (1/\nu_2)\ ((S\bar{x}_2^2)/(S\bar{x}_1^2 + Sx_2^2))^2$$

where: $\nu_1 = N_1 - 1$

$\nu_1 = N_2 - 2$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{S\bar{x}_1^2 + S\bar{x}_2^2}}$$

Read "t" table at t and DF to find confidence level at which a difference exists

Paired Comparison Test

1. Calculate S_{di}

where $S_d = \sqrt{\frac{\Sigma(dj - \bar{d})^2}{n-1}}$

and $\bar{d} = \bar{x} - \bar{y}$

$d_j = x - y$

n = number of pairs of data

x & y = data pair

$\bar{x}$ & $\bar{y}$ = average of each set of data

2. Calculate t;

$$\text{where } t = \frac{\bar{d}\sqrt{n}}{s_d}$$

Compare calculated "t" to table "t" to determine if there is a significant difference in the two sets of data.

Confidence Range

The Confidence Range was calculated by:

$$\text{Range} = \bar{x} \pm ts/\ \sqrt{n-1}$$

where $\bar{x}$ = mean value

t = value from "t" table at desired confidence range and degrees of freedom

s = standard deviation

n = number of pieces of data.

APPENDIX F

ENGLISH UNITS AND CONVERSION TO METRIC UNITS

English Unit	Abbreviation	Conversion Factor By	Metric Unit	Abbreviation
acre	ac	0.405	hectares	ha
acre - feet	ac ft	1233.5	cubic meters	cu m
cubic feet	cu ft	0.028	cubic meters	cu m
cubic feet	cu ft	28.32	liters	L
cubic feet/ minute	cfm	0.028	cubic meters/ minute	cu m/min
cubic feet/ second	cfs	1.7	cubic meters/ minute	cu m/min
cubic inches	cu in	16.39	cubic centimeters	cu cm
cubic yards	cu yd	0.7646	cubic meters	cu m
feet	ft	0.3048	meters	m
gallon	gal.	3.785	liters	L
gallon/minute	gpm	0.0631	liters/second	L/sec
gallons per day per square foot	gpd/sf	0.0407	cubic meters per day per square meter	m^3/m^2/day
horsepower	hp	0.7457	kilowatts	kw
inches	in	2.54	centimeters	cm
pounds	lb	0.454	kilograms	kg
million gallons/ day	mgd	3,785	cubic meters/ day	cu m/day
square feet	sq ft	0.0929	square meters	sq m
square inches	sq in	6.452	square centimeters	sq cm
tons (short) (2,000 lbs)	ST	0.907	metric tons (1000 kilograms)	kkg
tons (long) (2,240 lbs)	LT	0.016	metric tons (1000 kilograms)	kkg
yard	yd	0.9144	meters	m

NOTE: Multiply the value of the English Unit by the indicated conversion factor to get the value of the corresponding Metric Unit.